

Specifications for Structural Concrete

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This Specification is a Reference Specification that the Engineer or Architect can make applicable to any construction project by citing it in the Project Specifications. The Architect/Engineer supplements the provisions of this Reference Specification as needed by designating or specifying individual project requirements.

The document covers materials and proportioning of concrete; reinforcing and prestressing steels; production, placing, finishing, and curing of concrete; and formwork design and construction. Methods of treatment of joints and embedded items, repair of surface defects, and finishing of formed and unformed surfaces are specified. Separate sections are devoted to architectural concrete, lightweight concrete, mass concrete, prestressed concrete, and shrinkage-compensating concrete. Provisions governing testing, evaluation, and acceptance of concrete as well as acceptance of the structure are included.

Keywords: admixtures; aggregates; air entrainment; architectural concrete; buildings; cements; cold-weather construction; compressive strength; concrete construction; concrete durability; concrete slab; concretes; consolidation; conveying; curing; density; evaluation; exposed-aggregate finish; finishes; floors; formwork (construction); grouting; hot-weather construction; inspection; joints (contraction, construction, and isolation); lightweight concrete; materials; mixture proportioning; mixing; placing; prestressed concrete; prestressing steels; reinforced concrete; reinforcing steels; repairs; reshoring; shoring; shrinkage-compensating concrete; specifications; subgrades; temperature; tests; tolerances; water-cementitious materials ratio, (*w/cm*); welded wire fabric.

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FOREWORD

F1. This foreword is included for explanatory purposes only. It does not form a part of Specification ACI 301M.

F2. Specification ACI 301M is a Reference Specification that the Architect/Engineer may cite in the Project Specifications for any construction project, together with supplementary requirements for the specific project.

F3. Each technical section of Specification ACI 301M is written in the Three-Part Section Format of the Construction Specifications Institute, as adapted by ACI and modified to ACI requirements. The language is generally imperative and terse. The Specification is written to the Contractor. When a provision of this specification requires action on the Contractor's part, the verb "shall" is used. If the Contractor is allowed to exercise an option, the verb "may" or, when limited alternatives are available, the conjunctive phrase "shall either...or..." is used. Statements provided in the specification as information to the contractor use the verbs "may" or "will." Informational statements typically identify activities or options that "will" be taken or "may" be taken by the Owner or the Architect/Engineer.

F4. Checklists do not form a part of Reference Specification ACI 301M. Checklists are to assist the Architect/Engineer in properly choosing and specifying any necessary requirements for the Project Specifications.

SPECIFICATION

SECTION 1—GENERAL REQUIREMENTS

1.1—Scope

1.1.1 Work specified—This Reference Specification covers cast-in-place structural concrete.

Provisions of this Specification shall govern except where other provisions are specified in the Contract Documents.

1.1.2 Work not specified—The following subjects are not in the scope of this specification:

- Precast concrete products;
- Heavyweight shielding concrete;
- Slip-formed paving concrete;
- Terrazzo;
- Insulating concrete; and
- Refractory concrete.

1.2—Definitions

Acceptable or Accepted—Acceptable to or accepted by the Architect/Engineer.

ACI Concrete Field Testing Technician Grade 1—A person who has demonstrated knowledge and ability to perform and record the results of ASTM standard tests on freshly mixed concrete and to make and cure test specimens. Such knowledge and ability shall be demonstrated by passing prescribed written and performance examinations and having credentials that are current with the American Concrete Institute.

Architect/Engineer or Engineer/Architect—The Architect, Engineer, architectural firm, engineering firm, or architectural and engineering firm, issuing project drawings and specifications, or administering work under the Contract Documents.

Architectural concrete—Concrete that is exposed as an interior or exterior surface in the completed structure and is designated as architectural concrete in the Contract Documents; contributes to visual character of the completed structure and therefore requires special care in the selection of the concrete materials, forming, placing, and finishing to obtain the desired architectural appearance.

Backshores—Shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area without allowing the slab or member to deflect or support its own mass or existing construction loads from above.

Cement, expansive—A cement that, when mixed with water, produces a paste that, after setting, tends to increase in volume to a significantly greater degree than does portland cement paste; used to compensate for volume decrease due to shrinkage or induce tensile stress in reinforcement.

Cement, expansive Type K—A mixture of portland cement, anhydrous tetracalcium trialuminate sulfate ($C_4A_3\bar{S}$), calcium sulfate ($CaSO_4$), and lime (CaO); the $C_4A_3\bar{S}$ is a constituent of a separately burned clinker that is interground with portland cement or alternately, it may be formed simultaneously with the portland cement clinker compounds during the burning process.

Contract Documents—Documents, including the project drawings and Project Specifications, covering the required Work.

Contractor—Person, firm, or corporation with whom the Owner enters into an agreement for construction of the Work.

Exposed to public view—Situated so that it can be seen from a public location after completion of the building.

High-early-strength concrete—Concrete that, through the use of ASTM C 150 Type III cement or admixtures, is capable of attaining specified strength at an earlier age than normal concrete.

Lightweight concrete—Concrete of substantially lower density than normalweight concrete.

Mass concrete—Any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.

Mass concrete, plain—Mass concrete containing no reinforcement or less reinforcement than necessary to be considered reinforced mass concrete.

Mass concrete, reinforced—Mass concrete containing adequate reinforcement, prestressed or nonprestressed, designed to act together with the concrete in resisting forces including those induced by temperature and shrinkage.

Normalweight concrete—Concrete having a density of approximately 2400 kg/m³ made with gravel or crushed stone aggregates.

Owner—Corporation, association, partnership, individual, public body, or authority with whom the Contractor enters into agreement, and for whom the Work is provided.

Permitted—Accepted or acceptable to the Architect/Engineer usually pertaining to a request by the Contractor, or when specified in the Contract Documents.

Post-tensioning—A method of prestressing reinforced concrete in which tendons are tensioned after the concrete has hardened.

Prestressed concrete—Concrete where internal stresses of such magnitude and distribution are introduced that the tensile stresses resulting from the service loads are counteracted to a desired degree; in reinforced concrete, the prestress is commonly introduced by tensioning the tendons.

Project drawings—The drawings that, along with Project Specifications, complete the descriptive information for constructing the Work required or referred to in the Contract Documents.

Project Specifications—The written documents that specify requirements for a project in accordance with the service parameters and other specific criteria established by the Owner.

Reference specification—A specification that is intended by the Architect/Engineer to be a reference standard for the Contractor to use in the construction of a project by citing the reference specification in the Contract Documents, together with the project requirements.

Reference standards—Standards of a technical society, organization, or association, including the codes of local or state authorities, that are referenced in the Contract Documents.

Required—Required in this Reference Specification or the Contract Documents.

Reshores—Shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, thus requiring the new slab or structural member to deflect and support its own mass and existing construction loads applied before the installation of the reshores.

Shrinkage-compensating concrete—A concrete made using an expansive cement in which volume increases after setting, if properly elastically restrained, induce compressive stresses that are intended to approximately offset the tendency of drying shrinkage to induce tensile stresses.

Strength test—The average of the compressive strengths of two cylinders made from the same sample of concrete and tested at 28 days or at test age designated for determination of specified compressive strength f_c .

Structural lightweight concrete—Structural concrete made with lightweight aggregate; the density usually is in the range of 1450 to 1850 kg/m³.

Submitted—Submitted to the Architect/Engineer for review and acceptance.

Work—The entire construction or separately identifiable parts thereof that are required to be furnished under the Contract Documents; work is the result of performing services, furnishing labor, and furnishing and incorporating materials and equipment into the construction in accordance with the Contract Documents.

1.3—Reference standards and cited publications

1.3.1 Reference standards—Standards of ACI, ASTM, CRD, PTI, and AWS referred to in this Reference Specification are listed with serial designation including year of adoption or revision and are part of this Reference Specification.

1.3.1.1 ACI standards

ACI 117M-90 Specifications for Tolerances for Concrete Construction and Materials

1.3.1.2 ASTM standards

A 82-97a	Standard Specification for Steel Wire, Plain, for Concrete Reinforcement
A 184/	Standard Specification for Fabricated
A 184M-96	Deformed Steel Bar Mats for Concrete Reinforcement
A 185-97	Standard Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement
A 416/	Standard Specification for Steel Strand,
A 416M-98 ¹	Uncoated Seven-Wire, for Prestressed Concrete
A 421/	Standard Specification for Uncoated Stress-
A 421M-98a	Relieved Steel Wire for Prestressed Concrete
A 496-97a	Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement
A 497-97	Standard Specification for Steel Welded Wire Fabric, Deformed, for Concrete Reinforcement
A 615/	Standard Specification for Deformed and Plain
A 615M-96a	Billet-Steel Bars for Concrete Reinforcement
A 616/	Standard Specification for Rail-Steel Deformed
A 616M-96a	and Plain Bars for Concrete Reinforcement

A 617/ A 617M-96a A 706/ A 706M-98 ¹	Standard Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement	C 309-98a	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
A 722/ A 722M-98 A 767/ A 767M-97	Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement	C 330-99	Standard Specification for Lightweight Aggregates for Structural Concrete
A 775/ A 775M-97 ¹ A 779/ A 779M-98	Standard Specification for Uncoated High-Strength Steel Bars for Prestressing Concrete	C 387-99	Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete
A 780-93a	Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement	C 404-97	Standard Specification for Aggregates for Masonry Grout
A 884/ A 884M-96a ¹ A 934/ A 934M-97 ¹ A 955M-96	Standard Practice for Repair of Damaged Hot-Dip Galvanized Coatings	C 494-99	Standard Specification for Chemical Admixtures for Concrete
A 970/ A 970M-98 A 996/ A 996M-98	Standard Specification for Epoxy-Coated Steel Wire and Welded Wire Fabric for Reinforcement	C 567-99a	Standard Test Method for Density of Structural Lightweight Concrete
C 31/ C 31M-98 C 33-99 C 39/ C 39M-99 C 42/ C 42M-99	Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars	C 595-98	Standard Specification for Blended Hydraulic Cements
C 94/ C 94M-99 C 138-92	Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement	C 597-97	Standard Test Method for Pulse Velocity Through Concrete
C 143/ C 143M-98 C 150-99 C 171-97a	Standard Specification for Welded or Forged Headed Bars for Concrete Reinforcement	C 618-99	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 172-97 C 173-94a ¹	Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement	C 684-96	Standard Test Method for Making, Accelerated Curing, and Testing Concrete Compression Test Specimens
C 192/ C 192M-98 C 231-97 ¹	Standard Practice for Making and Curing Concrete Test Specimens in the Field	C 685-98a	Standard Specification for Concrete Made By Volumetric Batching and Continuous Mixing
C 260-98	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory	C 803/ C 803M-97 C 805-97	Standard Test Method for Penetration Resistance of Hardened Concrete
	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method	C 845-96	Standard Test Method for Rebound Number of Hardened Concrete
	Standard Specification for Air-Entraining Admixtures for Concrete	C 873-99	Standard Specification for Expansive Hydraulic Cement
		C 878-95a	Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
		C 881-99	Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete
		C 900-99	Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete
		C 928-99	Standard Test Method for Pullout Strength of Hardened Concrete
		C 989-99	Standard Specification for Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs
		C 1017/ C 1017M-98 C 1059-99	Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
		C 1064/ C 1064M-99 C 1074-98	Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
		C 1077-99	Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete
		C 1107-99	Standard Test Methods for Temperature of Freshly Mixed Portland Cement Concrete
			Standard Practice for Estimating Concrete Strength by the Maturity Method
			Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
			Standard Specification for Packaged Dry, Hydraulic Cement Grout (Nonshrink)

C 1150-96	Standard Test Method for the Break-Off Number of Concrete	American Concrete Institute (ACI) P.O. Box 9094 Farmington Hills, MI 48333-9094
C 1218/ C 1218M-99	Standard Test Method for Water-Soluble Chloride in Mortar and Concrete	American Society for Testing and Materials (ASTM) 100 Barr Harbor Drive West Conshohocken, PA 19428
C 1240-99	Standard Specification for Silica Fume for Use in Hydraulic-Cement Concrete, Mortar, and Grout	American Society for Testing and Materials (ASTM) 100 Barr Harbor Drive West Conshohocken, PA 19428
C 1315-95	Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete	American Welding Society (AWS) 550 N.W. Le Jeune Road P.O. Box 351040 Miami, FL 33135
D 98-95	Standard Specification for Calcium Chloride	American Welding Society (AWS) 550 N.W. Le Jeune Road P.O. Box 351040 Miami, FL 33135
D 994-98	Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)	Concrete Plant Manufacturers Bureau (CPMB) 900 Spring Street Silver Spring, MD 20910
D 1621-94	Standard Test Methods for Compressive Properties of Rigid Cellular Plastics	Concrete Plant Manufacturers Bureau (CPMB) 900 Spring Street Silver Spring, MD 20910
D 1751-99	Standard Specification for Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Non-extruding and Resilient Bituminous Types)	Concrete Reinforcing Steel Institute (CRSI) 933 N. Plum Grove Road Schaumburg, IL 60173
D 1752-84 (1996) ^{e1}	Standard Specification for Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction	U.S. Army Corps of Engineers [COE(CRD)] Waterways Experiment Station 3909 Halls Ferry Road Vicksburg, MS 39180
D 3575-93	Standard Test Methods for Flexible Cellular Materials Made from Olefin Polymers	U.S. Army Corps of Engineers [COE(CRD)] Waterways Experiment Station 3909 Halls Ferry Road Vicksburg, MS 39180
E 329-98a	Standard Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction	National Ready Mixed Concrete Association (NRMCA) 900 Spring Street Silver Spring, MD 20910
E 1155M-96	Standard Test Method for Determining Floor Flatness and Levelness Using the F-Number System	National Ready Mixed Concrete Association (NRMCA) 900 Spring Street Silver Spring, MD 20910
		Post Tensioning Institute (PTI) 1717 W. Northern Avenue #218 Phoenix, AZ 85021

1.3.1.3 Other referenced standards—Other standards referenced in this Reference Specification:

ANSI/	Structural Welding Code—Reinforcing
AWS D-1.4-98	Steel
CRD-C 513-74	Specification for Rubber Waterstops
CRD-C 572-74	Specification for Polyvinylchloride Waterstops
PTI 1993	Specification for Unbonded Single Strand Tendons

1.3.2 Cited publications—Publications cited in this Reference Specification:

ACI 318M-99	Building Code Requirements for Reinforced Concrete
ACI CP1-98	ACI Certification Concrete Field Testing Technician—Grade I
ACI SP-15M	Field Reference Manual
CRSI MSP-1-97	Manual of Standard Practice, 26th Edition

1.3.3 Field references—Keep in Contractor's field office a copy of the following reference:

SP-15M	Field Reference Manual: Specification for Structural Concrete (ACI 301M-99) with Selected ACI and ASTM References.
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1.4—Standards-producing organizations

Abbreviations for and complete names and addresses of organizations issuing documents referred to in this Reference Specification are listed:

1.5—Submittals

1.5.1 General—Unless otherwise specified, submittals required in this Reference Specification shall be submitted for review and acceptance.

1.5.2 Testing agency reports—Testing agencies shall report results of concrete and concrete materials tests and inspections performed during the course of the Work to the Owner, Architect/Engineer, Contractor, and the concrete supplier. Strength test reports shall include location in the Work where the batch represented by test was deposited and the batch ticket number. Reports of strength tests shall include detailed information of storage and curing of specimens before testing. Final reports shall be provided within 7 days of test completion.

1.6—Quality assurance

1.6.1 General—Concrete materials and operations may be tested and inspected by the Owner as work progresses. Failure to detect defective work or material early will not prevent rejection if a defect is discovered later nor shall it obligate the Architect/Engineer for final acceptance.

1.6.2 Testing agencies—Agencies that perform testing services on concrete materials shall meet the requirements of ASTM C 1077. Testing agencies that perform testing ser-

VICES on reinforcing steel shall meet the requirements of ASTM E 329. Testing agencies performing the testing shall be accepted by the Architect/Engineer before performing any work. Field tests of concrete required in 1.6.3 and 1.6.4 shall be made by an ACI Concrete Field Testing Technician Grade 1 in accordance with ACI CP1 or equivalent. Equivalent certification programs shall include requirements for written and performance examinations as stipulated in ACI publication CP1.

1.6.3 Testing responsibilities of Contractor

1.6.3.1 Submit data on qualifications of proposed testing agency for acceptance. Use of testing services will not relieve the Contractor of the responsibility to furnish materials and construction in full compliance with the Contract Documents.

1.6.3.2 Duties and responsibilities—Unless otherwise specified in the Contract Documents, the Contractor shall assume the following duties and responsibilities:

1.6.3.2.a Qualify proposed materials and establish mixture proportions.

1.6.3.2.b Furnish any necessary labor to assist Owner's testing agency in obtaining and handling samples at the project site or at the source of materials.

1.6.3.2.c Advise Owner's testing agency at least 24 hr in advance of operations to allow for completion of quality tests and for assignment of personnel.

1.6.3.2.d Provide and maintain for the sole use of the testing agency adequate facilities for safe storage and proper curing of concrete test specimens on the project site for initial curing as required by ASTM C 31/C 31M.

1.6.3.2.e Submit data and test documentation on materials and mixture proportions.

1.6.3.2.f Submit quality-control program of the concrete supplier and provide copies of test reports pertaining to the work.

1.6.3.2.g When specified or permitted to base concrete acceptance on accelerated strength testing, submit correlation data for the standard 28-day compressive strength based on at least 15 sets of test data in accordance with 1.6.4.2.d with concrete made with the same materials providing a range of at least the required average strength f_{cr} , plus or minus 7 MPa.

1.6.3.3 Tests required of Contractor's testing agency—Unless otherwise specified in the Contract Documents, the Contractor shall provide at no cost to the Owner the necessary testing services for the following:

1.6.3.3.a Qualification of proposed materials and establishment of concrete mixtures.

1.6.3.3.b Other testing services needed or required by Contractor.

1.6.4 Testing responsibilities of Owner's testing agency

1.6.4.1 Unless otherwise specified in the Contract Documents, the Owner's testing agency will provide the necessary services for the following:

1.6.4.1.a Representatives of the Owner's testing agency will inspect, sample, and test materials and production of concrete required by the Architect/Engineer. When it appears that material furnished or work performed by the Contractor

fails to conform to Contract Documents, the testing agency will immediately report such deficiency to the Architect/Engineer, Contractor, and concrete supplier.

1.6.4.1.b The testing agency and its representatives are not authorized to revoke, alter, relax, enlarge, or release any requirement of the Contract Documents, nor to accept any portion of the Work.

1.6.4.1.c The testing agency will report test and inspection results that pertain to the Work to the Architect/Engineer, Contractor, and concrete supplier within 7 days after tests and inspections are performed.

1.6.4.2 Testing services—When required by the Owner or the Architect/Engineer, the Owner's testing agency will perform the following testing services at no cost to the Contractor:

1.6.4.2.a Review and check-test proposed materials for compliance with Contract Documents.

1.6.4.2.b Review and check-test proposed concrete mixture as required by the Architect/Engineer.

1.6.4.2.c Obtain production samples of materials at plants or stockpiles during the course of the Work and test for compliance with the Contract Documents.

1.6.4.2.d Obtain samples in accordance with ASTM C 172. Select the trucks or batches of concrete to be tested on a random basis, using random numbers selected before commencement of concrete placement.

Obtain at least one composite sample for each 80 m³, or fraction thereof, of each concrete mixture placed in any one day. When the total quantity of a given concrete mixture is less than 40 m³, the strength tests may be waived by the Architect/Engineer.

1.6.4.2.e Conduct strength tests of concrete during construction in accordance with the following procedures:

- Mold and cure three cylinders from each sample in accordance with ASTM C 31/C 31M. Record any deviations from the ASTM requirements in the test report.
- Test cylinders in accordance with ASTM C 39/C 39M. Test one specimen at 7 days for information, and two specimens at 28 days for acceptance, unless otherwise specified. The compressive strength test results for acceptance shall be the average of the compressive strengths from the two specimens tested at 28 days. If one specimen in a test shows evidence of improper sampling, molding, or testing, discard the specimen and consider the strength of the remaining cylinder to be the test result. If both specimens in a test show any defects, discard the entire test.
- When accelerated testing of concrete is specified or permitted as an alternative to standard testing, mold and cure two specimens from each composite sample in accordance with ASTM C 684, following the procedure specified by the Architect/Engineer. Make at least one accelerated strength test from each composite sample in 1.6.4.2.d and one standard 28-day compressive-strength test for at least every other accelerated strength test in accordance with ASTM C 31/C 31M. Use these test results to maintain and update the correlation between accelerated and standard 28-day compressive-strength tests.

1.6.4.2.f Determine slump of each composite sample taken in accordance with 1.6.4.2.d and whenever consistency of concrete appears to vary, using ASTM C 143/C 143M.

1.6.4.2.g Determine the temperature of each composite sample taken in accordance with 1.6.4.2.d using ASTM C 1064/C 1064M.

1.6.4.2.h Determine the air content of normalweight concrete using ASTM C 231, C 173, or C 138 for each composite sample taken in accordance with 1.6.4.2.d or as directed by the Architect/Engineer. Additional tests will be performed as necessary.

1.6.4.2.i Where concrete will be exposed to deicing salts as indicated in the Contract Documents, air content tests will be made on samples from the first three batches in the placement and until three consecutive batches have air contents within the range specified in 4.2.2.4—Air content, at which time every fifth batch will be tested. This test frequency will be maintained until a batch is not within the range specified in 4.2.2.4, at which time testing of each batch will be resumed until three consecutive batches have air contents within the range specified in 4.2.2.4. Additional tests may be performed as necessary for control. These air content tests may be taken on composite samples in 1.6.4.2.d or on samples from the batch at any time after discharge of 0.1 m³ of concrete.

1.6.4.3 Additional testing services when required—The Owner's testing agency will perform the following testing services when required by the Architect/Engineer, at no cost to the Contractor:

- Inspect concrete batching, mixing, and delivery operations;
- Inspect forms, foundation preparation, reinforcing steel, embedded items, reinforcing steel placing, and concrete placing, finishing, and curing operations;
- Sample concrete at point of placement and other locations as directed by the Architect/Engineer and perform required tests;
- Review the manufacturer's report for each shipment of cement, reinforcing steel, and prestressing tendons, and conduct laboratory tests or spot checks of the materials received for compliance with specifications; and
- Other testing or inspection services as required by the Architect/Engineer.

1.6.4.4 Other testing services as needed—The contractor shall pay for the following testing services performed, when necessary, by the Owner's testing agency:

- Additional testing and inspection required because of changes in materials or mixture proportions requested by the Contractor; and
- Additional testing of materials or concrete occasioned by failure to meet specification requirements.

1.6.5 Tests on hardened concrete in-place

1.6.5.1 General—Tests on hardened concrete will be performed by the Owner's testing agency when such tests are needed. Testing shall be at the Contractor's expense when tests are performed to verify the strength of the structure when required by this specification. The Owner will pay costs if tests are at the Owner's request and not required by this Specification.

1.6.5.2 Nondestructive tests—Use of the rebound hammer in accordance with ASTM C 805, pulse-velocity method in accordance with ASTM C 597, or other nondestructive tests may be permitted by the Architect/Engineer in evaluating the uniformity and relative concrete strength in-place, or for selecting areas to be cored.

1.6.5.3 Core tests

1.6.5.3.a Where required by the Architect/Engineer, cores shall be obtained and tested in accordance with ASTM C 42/C 42M. If concrete in the structure will be dry under service conditions, the cores shall be air dried [temperature 16 to 27 C, relative humidity less than 60%] for 7 days before testing and shall be tested dry. If concrete in the structure will be more than superficially wet under service conditions, the core shall be tested after moisture conditioning in accordance with ASTM C 42/C 42M.

1.6.5.3.b At least three representative cores shall be taken from each member or area of concrete in place that is considered potentially deficient. The location of cores as determined by the Architect/Engineer shall impair the strength of the structure as little as possible. If, before testing, cores show evidence of having been damaged subsequent to or during removal from the structure, replacement cores shall be taken.

1.6.5.3.c Fill core holes with low-slump concrete or mortar of a strength equal to or greater than the original concrete.

1.6.6 Evaluation of concrete strength tests

1.6.6.1 Standard molded and cured strength specimens—Test results from standard molded and cured test cylinders shall be evaluated separately for each specified concrete mixture. Evaluation will be valid only if tests have been conducted in accordance with procedures specified. For evaluation, each specified mixture shall be represented by at least five tests.

1.6.6.2 Nondestructive tests—Test results will be evaluated by the Architect/Engineer and will be valid only if tests have been conducted using properly calibrated equipment in accordance with recognized standard procedures and an acceptable correlation between test results and concrete compressive strength has been established and is submitted.

1.6.6.3 Core tests—Core test results will be evaluated by the Architect/Engineer and will be valid only if tests have been conducted in accordance with specified procedures.

1.6.7 Acceptance of concrete strength

1.6.7.1 Standard molded and cured strength specimens—The strength level of concrete will be considered satisfactory when the averages of all sets of three consecutive compressive strength test results equal or exceed the specified compressive strength f_c , and no individual strength test result falls below the specified compressive strength f_c by more than 3.4 MPa. These criteria apply also when accelerated strength testing is specified unless another basis for acceptance is specified in the Contract Documents.

1.6.7.2 Nondestructive tests—Nondestructive tests shall not be used as the sole basis for accepting or rejecting

concrete, but may be used when permitted to evaluate concrete where standard molded and cured cylinders have yield results not meeting the criteria in 1.6.7.1.

1.6.7.3 Core tests—Strength level of concrete in the area represented by core tests will be considered adequate when the average compressive strength of the cores are equal to at least 85% of specified compressive strength f_c , and if no single core is less than 75% of the specified compressive strength f_c .

1.6.8 Field acceptance of concrete

1.6.8.1 Air content—Concrete not within the limits of air-entrainment indicated in 4.2.2.4 and tested in accordance with 1.6.4.2.h shall not be used in the Work.

1.6.8.2 Slump—Concrete not within the slump limits of 4.2.2.2 at the point of placement shall not be used in the Work.

1.6.8.3 Temperature—Concrete not within temperature limits of 4.2.2.7 shall not be used in the Work.

1.7—Acceptance of structure

1.7.1 General—Completed concrete work shall conform to applicable requirements of this Reference Specification and the Contract Documents.

1.7.1.1 Concrete work that fails to meet one or more requirements of the Contract Documents but subsequently is repaired to bring the concrete into compliance may be accepted.

1.7.1.2 Concrete work that fails to meet one or more requirements of the Contract Documents and cannot be brought into compliance may be rejected.

1.7.1.3 Repair rejected concrete work by removing and replacing or by reinforcing with additional construction required by the Architect/Engineer. To bring rejected work into compliance, use repair methods that will maintain specified strength and meet applicable requirements for function, durability, dimensional tolerances, and appearance as determined by the Architect/Engineer.

1.7.1.4 Submit for acceptance the proposed repair methods, materials, and modifications needed to assure that concrete work will meet requirements of Contract Documents.

1.7.1.5 Contractor shall pay all costs to bring concrete work into compliance with requirements of Project Specification.

1.7.1.6 Concrete members cast in the wrong location may be rejected.

1.7.2 Dimensional tolerances

1.7.2.1 Formed surfaces resulting in concrete outlines smaller than permitted by the tolerances of ACI 117M, may be considered deficient in strength and subject to the provisions of 1.7.4—Strength of structure.

1.7.2.2 Formed surfaces resulting in concrete outlines larger than permitted by ACI 117M may be rejected. Remove excess materials when required by the Architect/Engineer.

1.7.2.3 Inaccurately formed concrete surfaces that exceed ACI 117M tolerances may be rejected.

1.7.2.4 Finished slabs exceeding the tolerances in 5.3.4.3—Finishing tolerances for slabs, may be corrected provided strength or appearance are not adversely affected.

1.7.2.5 Concrete with tolerances and defects exceeding the limitations of 2.2.2.4 may be rejected.

1.7.3 Appearance

1.7.3.1 Concrete not meeting the requirements of 5.3.3—Finishing formed surfaces, or 5.3.4—Finishing unformed surfaces shall be brought into compliance in accordance with 1.7.1—General.

1.7.4 Strength of structure

1.7.4.1 Criteria for determining potential strength deficiency—Strength will be considered deficient and concrete work will be rejected when the work fails to comply with requirements that control the strength of the structure including, but not limited to, the following conditions:

1.7.4.1.a Concrete strength failing to comply with requirements of 1.6.7—Acceptance of concrete strength.

1.7.4.1.b Reinforcing steel size, quantity, strength, position, or arrangement at variance with the requirements of Section 3—Reinforcement and reinforcement supports, or other Contract Documents.

1.7.4.1.c Concrete elements that differ from the required dimensions or location.

1.7.4.1.d Curing not in accordance with Contract Documents.

1.7.4.1.e Inadequate protection of concrete from extreme temperature and other environmental conditions during early stages of hardening and strength development.

1.7.4.1.f Mechanical injury, construction fires, accidents, or premature removal of formwork resulting in deficient strength.

1.7.4.2 Action required when strength is potentially deficient—When strength of the structure is considered potentially deficient, the following actions may be required by the Architect/Engineer:

1.7.4.2.a Structural analysis or additional testing, or both.

1.7.4.2.b Core tests.

1.7.4.2.c If testing is inconclusive or impractical or if structural analysis does not confirm the safety of the structure, load tests may be required and their results evaluated in accordance with ACI 318.

1.7.4.2.d Concrete work rejected by structural analysis or by results of a load test shall be strengthened with additional construction when required by the Architect/Engineer, or replaced.

1.7.4.2.e Document all repair work proposed to bring strength-deficient concrete work into compliance with Contract Documents, and submit the documentation to the Architect/Engineer for acceptance.

1.7.5 Durability

1.7.5.1 Criteria for determining potential durability deficiency—Durability of concrete work will be considered deficient and the concrete work will be rejected when it fails to comply with the requirements that control durability of the structure including, but not limited to, the following conditions:

1.7.5.1.a—Strength failing to comply with 1.6.7—Acceptance of concrete strength.

1.7.5.1.b—Materials for concrete not conforming with the requirements in **4.2.1.1**—Cements, **4.2.1.2**—Aggregates, **4.2.1.3**—Water, and **4.2.1.4**—Admixtures, including air-entrainment.

1.7.5.1.c—Concrete not conforming with the air-entrainment requirements in Contract Documents or the air content limits of **Table 4.2.2.4**.

1.7.5.1.d—Curing not in accordance with Contract Documents.

1.7.5.1.e—Inadequate protection of concrete from temperature and other environmental conditions during early stages of hardening and strength development.

1.7.5.1.f—Concrete not conforming to the maximum allowable chloride-ion content requirements in **Table 4.2.2.6**.

1.7.5.2 *Action required when durability is potentially deficient*—When durability of the structure is considered to be deficient, the following actions may be required by the Architect/Engineer:

1.7.5.2.a—Obtain and test samples of the ingredient materials used in the concrete.

1.7.5.2.b—Obtain samples of concrete from the structure by coring, sawing, or other acceptable means.

1.7.5.2.c—Laboratory evaluation of concrete and concrete materials to assess the ability of concrete to resist weathering action, chemical attack, abrasion, reinforcement corrosion, or other deterioration.

1.7.5.2.d—Repair or replace concrete rejected for lack of durability as directed by the Architect/Engineer.

1.7.5.2.e—Document repair work to bring concrete work into compliance with Contract Documents and submit the documentation to the Architect/Engineer for acceptance.

1.8—Protection of in-place concrete

1.8.1 *Loading and support of concrete*—Do not allow construction loads to exceed the superimposed load that the structural member, with necessary supplemental support, is capable of carrying safely and without damage.

1.8.2 *Protection from mechanical injury*—During the curing period, protect concrete from damaging mechanical disturbances including load stresses, shock, and harmful vibration. Protect concrete surfaces from damage by construction traffic, equipment, materials, rain or running water, and other adverse weather conditions.

SECTION 2—FORMWORK AND FORMWORK ACCESSORIES

2.1—General

2.1.1 *Description*—This section covers design, construction, and treatment of formwork to confine and shape concrete to the required dimensions.

2.1.2 Submittals

2.1.2.1 Submit the following data unless otherwise specified:

a. *Formwork facing materials*—Data on form-facing materials proposed for smooth-form finish if different from that specified in 2.2.1.1—Form-facing materials.

b. *Construction and contraction joints*—Location of construction and contraction joints proposed if different from those indicated in the Contract Documents.

c. *Testing for formwork removal*—Data on method for determining strength of concrete for removal of formwork in accordance with **2.3.4.2** when a method other than field-cured cylinders is proposed.

d. *Formwork removal plans*—Detail plans for formwork removal operations when removal of forms at concrete strengths lower than that specified in **2.3.2.5** is proposed.

e. *Reshoring and backshoring plans*—When reshoring or backshoring is required or permitted, submit procedures and plans of operations, before use, sealed by a professional Engineer licensed in the state where work will be performed.

f. Data on formwork release agent or form liner proposed for use with each formed surface.

2.1.2.2 Submit the following when required by the Contract Documents:

a. Shop drawings for formwork sealed by a professional Engineer licensed in the state where the work will be done.

b. Calculations for formwork, reshoring and backshoring, sealed by a professional Engineer licensed in the state where the work will be done.

c. Manufacturer's data and samples of form ties.

d. Manufacturer's data and samples of expansion joint materials.

e. Manufacturer's data and samples of waterstops.

2.2—Products

2.2.1 Materials

2.2.1.1 *Form-facing materials*—Materials for form facings in contact with concrete shall meet **5.3.3.5**—Unspecified finishes, and the following requirements unless otherwise specified in Contract Documents.

- For rough form finish—No form-facing material is specified.
- For smooth form finish—Use plywood, tempered concrete-form-grade hardboard, metal, plastic, paper, or other acceptable materials capable of producing the desired finish for form-facing materials. Form-facing materials shall produce a smooth, uniform texture on the concrete. Do not use form-facing materials with raised grain, torn surfaces, worn edges, patches, dents, or other defects that will impair the texture of concrete surfaces.

2.2.1.2 *Formwork accessories*—Use commercially manufactured accessories for formwork accessories that are partially or wholly embedded in concrete, including ties and hangers. Do not use nonfabricated wire form ties. Where indicated in the Contract Documents, use form ties with integral water barrier plates in walls.

2.2.1.3 *Formwork release agents*—Use commercially manufactured formwork release agents that will prevent formwork absorption of moisture, prevent bond with concrete, and not stain the concrete surfaces.

2.2.1.4 *Expansion joint filler*—Premolded expansion joint filler shall conform to ASTM D 994, D 1751, or D 1752.

2.2.1.5 *Other embedded items*—Use waterstops, sleeves, inserts, anchors, and other embedded items of the material and design indicated in the Contract Documents. Waterstop materials shall meet requirements of CRD C 513

for rubber waterstop, or CRD C 572 for polyvinylchloride waterstop. Make splices in waterstops and use molded pieces as recommended by the manufacturer.

2.2.2 Performance and design requirements

2.2.2.1 Design and engineering of formwork shall be the responsibility of the Contractor. When required by the Contract Documents, design calculations for formwork and formwork drawings shall be sealed by a professional Engineer licensed in the state where the work will be done.

2.2.2.2 Design formwork, shores, reshores, and backshores to carry all loads transmitted to them and to comply with the requirements of the applicable building code. Design formwork to withstand the pressure resulting from placement and vibration of concrete and to maintain specified tolerances.

2.2.2.3 Do not use earth cuts as forms for vertical or sloping surfaces unless required or permitted by Contract Documents.

2.2.2.4 Maximum deflection of facing materials reflected on concrete surfaces exposed to public view shall be 1/240 of the span between structural members of the formwork. For architectural concrete, see **6.2.2.1.a**.

2.2.2.5 Formed construction and contraction joints

2.2.2.5.a Locate and form construction joints that least impair strength of the structure and meet the requirements of **5.3.2.6**—Construction joints and other bonded joints.

2.2.2.5.b Unless otherwise specified or permitted, locate and detail formed construction joints to the following requirements:

- Locate construction joints within the middle third of the spans of slabs, beams, and girders. When a beam intersects a girder at this point, offset the joint in the girder a distance equal to or greater than twice the width of the beam.
- Locate joints in walls and columns at the underside of floors, slabs, beams, or girders and at the tops of footings or floor slabs.
- Make joints perpendicular to the main reinforcement.

2.2.2.5.c Provide keyways as indicated on Contract Documents. Where longitudinal keyways are indicated on the Contract Documents make them a minimum of 40 mm deep in joints in walls and between walls and slabs or footings.

2.2.2.5.d Provide construction and contraction joints where indicated on the Contract Documents. Submit for acceptance the location of construction and contraction joints differing from those indicated on the Contract Documents.

2.2.2.6 For a smooth-form finish, set the facing materials in an orderly and symmetrical arrangement, and keep the number of seams to a practical minimum. Support facing materials with studs or other backing capable of preventing excessive deflection within the tolerances specified in **2.2.2.4**.

2.2.3 Fabrication and manufacture

2.2.3.1 Formwork shall be tight to prevent loss of mortar from concrete.

2.2.3.2 Place 20 mm minimum chamfer strips in the corners of formwork to produce beveled edges on permanently exposed surfaces unless otherwise specified. Do not bevel

re-entrant corners or edges of formed joints of concrete unless specified in the Contract Documents.

2.2.3.3 Provide temporary openings at the base of column and wall formwork and at other points where necessary to facilitate cleaning and inspection. Clean and inspect immediately before concrete is placed.

2.2.3.4 Fabricate form ties so ends or end fasteners can be removed with minimum spalling at the faces of concrete.

After the ends or end fasteners of form ties have been removed, terminate the embedded portion of ties not less than two diameters, or twice the minimum cross-sectional dimension of the tie, from the formed concrete surface. In no case shall this distance be less than 20 mm. Repair tie holes in accordance with **5.3.7.2**—Repair of tie holes.

2.2.3.5 Locate waterstops in joints where indicated on Contract Documents. Use pieces of premolded waterstop with a maximum practicable length to hold the number of end joints to a minimum. Make joints in waterstops in accordance with the manufacturer's recommendations. Ensure that joints develop effective watertightness equal to the continuous waterstop material, permanently develop not less than 50% of the mechanical strength of the parent section and permanently retain flexibility.

2.3—Execution

2.3.1 Construction and erection of formwork

2.3.1.1 At construction joints, lap contact surface of the form sheathing for flush surfaces exposed to view over the hardened concrete in the previous placement by not more than 25 mm.

Ensure formwork is held firmly against hardened concrete to prevent offsets or loss of mortar at construction joints and to maintain a true surface.

2.3.1.2 Unless otherwise specified in the Contract Documents, construct formwork so concrete surfaces conform to the tolerance limits of ACI 117M. The class of surface for offset between adjacent pieces of formwork facing material shall be Class A for surfaces permanently exposed to public view and Class C for surfaces that will be permanently concealed, unless otherwise specified.

2.3.1.3 Provide positive means of adjustment (wedges or jacks) of shores and struts. Do not make adjustments in the formwork after concrete has reached its time of initial setting. Brace formwork securely against lateral deflection and lateral instability.

2.3.1.4 To maintain specified tolerances, camber formwork to compensate for anticipated deflections in formwork before hardening of concrete. Set formwork and intermediate screed strips for slabs accurately to produce designated elevations and contours of the finished surface before removal of formwork. Ensure that edge forms and screed strips are sufficiently strong to support vibrating screeds or roller pipe screeds when the finish specified requires the use of such equipment.

2.3.1.5 When formwork is cambered, set screeds to a like camber to maintain required concrete thickness.

2.3.1.6 Fasten form wedges in place after final adjustment of forms and before concrete placement.

2.3.1.7 Anchor formwork to shores, supporting surfaces, or members to prevent upward or lateral movement of the formwork system during concrete placement.

2.3.1.8 Construct formwork for wall openings to facilitate removal and to counteract swelling of wood formwork.

2.3.1.9 Provide runways for moving equipment and support runways directly on the formwork or structural member without resting on the reinforcing steel.

2.3.1.10 Place sleeves, inserts, anchors, and embedded items required for adjoining work or for support of adjoining work before concrete placement.

2.3.1.11 Position and support expansion joint materials, waterstops, and other embedded items to prevent displacement. Fill voids in sleeves, inserts, and anchor slots temporarily with readily removable material to prevent entry of concrete into voids.

2.3.1.12 Clean surfaces of formwork and embedded materials of mortar, grout, and foreign materials before concrete is placed.

2.3.1.13 Cover surfaces of formwork with an acceptable material that will prevent bond with the concrete. A field-applied formwork release agent or a factory-applied liner may be used. If a formwork release agent is used, apply to the surfaces of the formwork in accordance with the manufacturer's recommendations before placing reinforcing steel. Do not allow formwork release agent to puddle in the forms. Do not allow formwork release agent to contact reinforcing steel or hardened concrete against which fresh concrete is to be placed.

2.3.2 Removal of formwork

2.3.2.1 When finishing is required, remove forms as soon as removal operations will not damage concrete.

2.3.2.2 Remove top forms on sloping surfaces of concrete as soon as removal will not allow concrete to sag. Perform needed repairs or treatment required at once and follow immediately with specified curing.

2.3.2.3 Loosen wood formwork for wall openings when this can be accomplished without causing damage to the concrete.

2.3.2.4 Do not allow removal of formwork for columns, walls, sides of beams, and other parts not supporting the mass of the concrete to damage the concrete. Perform needed repair and treatment required on vertical surfaces at once and follow immediately with specified curing.

2.3.2.5 Unless otherwise specified, leave formwork and shoring in place to support the mass of concrete in beams, slabs, and in-place structural members until concrete has reached the specified compressive strength f_c in accordance with 2.3.4—Strength of concrete required for removal of formwork. If a lower compressive strength is proposed for removal of formwork and shoring, submit detailed plans for review and acceptance. When shores and other vertical supports are arranged to allow the form-facing material to be removed without loosening or disturbing the shores and supports, the facing material may be removed at an earlier age unless otherwise specified.

2.3.2.6 Construct formwork to permit easy removal.

2.3.3 Reshoring and backshoring

2.3.3.1 Submittals for reshoring and backshoring operations shall comply with 2.1.2.1 and 2.1.2.2.

2.3.3.2 While reshoring or backshoring is under way, do not permit any construction load on new construction.

2.3.3.3 During reshoring and backshoring do not allow concrete in beam, slab, column, or any structural member to be loaded with combined dead and construction loads in excess of the loads permitted by the Architect/Engineer for the concrete compressive strength at the time of reshoring and backshoring.

2.3.3.4 Place reshores and backshores in sequence with stripping operations.

2.3.3.5 Tighten reshores and backshores to carry the required loads without overstressing the concrete members. Leave them in place until tests required by 2.3.4—Strength of concrete required for removal of formwork, indicate that the concrete compressive strength has attained the minimum value specified in 2.3.2.5.

2.3.3.6 For floors supporting shores under newly placed concrete, either leave the original supporting shores in place, or install reshores or backshores. The shoring system and the supporting slabs shall have capacities sufficient to resist the anticipated loads. Locate reshores and backshores directly under a shore position.

2.3.3.7 In multistory buildings, extend reshoring or backshoring over a sufficient number of stories to distribute the mass of newly placed concrete, forms, and construction live loads such that the design loads of the floors supporting the shores, reshores or backshores are not exceeded.

2.3.4 Strength of concrete required for removal of formwork

2.3.4.1 When removal of formwork or reshoring is based on concrete reaching a specified compressive strength, concrete will be presumed to have reached this strength when test cylinders, field cured the same as the concrete they represent, have reached the compressive strength specified for removal of formwork or reshoring. Mold cylinders in accordance with ASTM C 31/C 31M, and cure them under the same conditions for moisture and temperature as used for the concrete they represent. Test cylinders in accordance with ASTM C 39/C 39M.

2.3.4.2 Alternatively, when specified or permitted, use one of the following methods for evaluating concrete strength for formwork removal. Before using methods in 2.3.4.2.b through 2.3.4.2.e, submit sufficient data using project materials to demonstrate correlation of measurements on the structure with the compressive strength of laboratory-cured molded cylinders or drilled cores. Submit correlation data on the proposed alternative method for determining strength to the Architect/Engineer.

2.3.4.2.a Tests of cast-in-place cylinders in accordance with ASTM C 873. This is limited to slabs with concrete depths from 130 to 300 mm.

2.3.4.2.b Penetration resistance in accordance with ASTM C 803/C 803M.

2.3.4.2.c Pullout strength in accordance with ASTM C 900.

2.3.4.2.d Acceptable maturity-factor procedure in accordance with ASTM C 1074.

2.3.4.2.e Break-off number of concrete in accordance with ASTM C 1150.

2.3.5 Field quality control

2.3.5.1 Establish and maintain controls and benchmarks in an undisturbed condition until final completion and acceptance of the project.

2.3.5.2 Variations from plumb and designated building lines shall not exceed the tolerances specified in ACI 117M.

SECTION 3—REINFORCEMENT AND REINFORCEMENT SUPPORTS

3.1—General

This section covers materials, fabrication, placement, and tolerances of reinforcement and reinforcement accessories.

3.1.1 Submittals, data, and drawings—Unless otherwise required by Contract Documents, submit the following data and drawings for review and acceptance before fabrication and execution:

3.1.1.1 Submit the following data unless otherwise specified:

a. *Placing drawings*—Submit placing drawings showing fabrication dimensions and locations for placement of reinforcement and reinforcement supports.

b. *Splices*—Submit a list and request to use splices not indicated in Contract Documents.

c. *Mechanical splices*—Submit request for the use of mechanical splices not shown on the project drawings.

d. *Column dowels*—Submit requests for placement of column dowels without the use of templates.

e. *Field bending*—Submit requests and procedure to field bend or straighten reinforcement partially embedded in concrete.

3.1.1.2 Submit the following data when required:

a. *Welding*—Submit description of reinforcement weld locations, welding procedures, and welder qualifications when welding is permitted in accordance with 3.2.2.2—Welding.

b. *Supports*—If coated reinforcement is required, submit description of reinforcement supports not described in 3.3.2.4—Reinforcement supports, and materials for fastening coated reinforcement.

3.1.1.3 Submit the following data when alternatives are proposed:

a. *Reinforcement relocation*—Submit a request to relocate any reinforcement that exceeds placement tolerances.

3.1.2 Materials delivery, storage, and handling

3.1.2.1 Prevent bending, coating with earth, oil, or other material, or otherwise damaging the reinforcement.

3.1.2.2 For handling coated reinforcement, use equipment having contact areas padded to avoid damaging the coating. Lift bundles of coated reinforcement at multiple pick-up points to prevent bar-to-bar abrasion from sags in the bundles. Do not drop or drag coated reinforcement. Store coated reinforcement on cribbing that will not damage the coating.

3.2—Products

3.2.1 Materials

3.2.1.1 Reinforcing bars—Use deformed bars as reinforcement except spirals and welded wire fabric, which may be plain. Reinforcement shall be the grades, types, and sizes

required by Contract Documents and shall conform to one of the following:

- ASTM A 615/A 615M;
- ASTM A 616/A 616M, including supplementary requirement S1;
- ASTM A 617/A 617M;
- ASTM A 706/A 706M;
- ASTM A 970/A 970M; or
- ASTM A 996/A 996M, rail-steel bars shall be Type R.

3.2.1.2 Coated reinforcing bars—Use zinc- or epoxy-reinforcing-bar coatings where required as specified in the Contract Documents.

3.2.1.2.a Zinc-coated (galvanized) reinforcing bars shall conform to ASTM A 767/A 767M.

Repair coating damage due to shipping, handling, and placing in accordance with ASTM A 780. The maximum amount of repaired damaged areas shall not exceed 2% of the surface area in each 300 mm of each bar.

3.2.1.2.b Epoxy-coated reinforcing bars shall conform to ASTM A 775/A 775M or ASTM A 934/A 934M as specified in the Contract Documents. Repair damaged areas with patching material conforming to ASTM A 775/A 775M or ASTM A 934/A 934M as applicable and in accordance with the material manufacturer's written recommendations. Repair coating damage due to shipping, handling, and placing. The maximum amount of repaired damaged areas shall not exceed 2% of the surface area in each linear foot of each bar. Fading of the coating color will not be cause for rejection of epoxy-coated reinforcing bars.

3.2.1.3 Stainless steel bars—Stainless steel bars shall conform to ASTM A 955M

3.2.1.4 Bar mats—Use bar mats of the clipped type conforming to ASTM A 184/A 184M and assembled from one of the following combinations specified:

- Bars conforming to ASTM A 615/A 615M, ASTM A 616/A 616M including supplementary requirement S1, ASTM A 617/A 617M, or ASTM A 706/A 706M;
- Zinc-coated (galvanized) bars conforming to ASTM A 767/A 767M and zinc-coated (galvanized) or nonmetallic clips, with any damage to coatings repaired in accordance with 3.2.1.2.a; or
- Epoxy-coated bars conforming to ASTM A 775/A 775M or ASTM A 934/A 934M and epoxy-coated or nonmetallic clips with any damage to coatings repaired in accordance with 3.2.1.2.b.

3.2.1.5 Wire—Use plain or deformed wire as indicated on Contract Documents. Plain wire may be used for spirals.

3.2.1.5.a Plain wire shall conform to ASTM A 82.

3.2.1.5.b Deformed wire size D4 and larger shall conform to ASTM A 496.

3.2.1.5.c Epoxy-coated wire shall conform to ASTM A 884/A 884M.

3.2.1.5.d For wire with a specified yield strength f_y exceeding 420 MPa, f_y shall correspond to a strain of 0.35%.

3.2.1.6 Welded wire fabric—Use welded wire fabric specified in Contract Documents and conforming to one of the following specifications:

3.2.1.6.a Plain wire fabric—ASTM A 185, with welded intersections spaced not farther apart than 300 mm in the direction of principal reinforcement.

3.2.1.6.b Deformed wire fabric—ASTM A 497, with welded intersections spaced not farther apart than 400 mm in the direction of principal reinforcement.

3.2.1.6.c Epoxy-coated welded wire fabric shall conform to ASTM A 884/A 884M.

3.2.1.6.d For welded wire fabric with a specified yield strength f_y exceeding 420 MPa, f_y shall correspond to a strain of 0.35%.

3.2.1.7 Wire-reinforcement supports—Unless otherwise specified or permitted, use wire-reinforcement supports complying with Class 1, maximum protection, or Class 2, moderate protection as indicated in Chapter 3—Bar Supports of the CRSI Manual of Standard Practice.

3.2.1.8 Coated wire-reinforcement supports

3.2.1.8.a For epoxy-coated reinforcement—Use wire-reinforcement supports coated with dielectric material including epoxy or another polymer for a minimum distance of 50 mm from the point of contact with epoxy-coated reinforcement.

3.2.1.8.b For zinc-coated reinforcement—Use galvanized wire-reinforcement supports or wire-reinforcement supports coated with dielectric material.

3.2.1.9 Precast concrete reinforcement supports—For supporting reinforcement use concrete supports that have a surface area of not less than 2500 mm² and have a compressive strength equal to or greater than the specified compressive strength of the concrete being placed.

3.2.2 Fabrication

3.2.2.1 Reinforcement—Bend reinforcement cold unless heating is permitted.

Fabricate reinforcement in accordance with fabricating tolerances of ACI 117M.

3.2.2.2 Welding

3.2.2.2.a When welding of reinforcement is specified or permitted, comply with the requirements of ANSI/AWS D1.4. Do not weld crossing bars (tack welding) for assembly of reinforcement, supports, or embedded items.

3.2.2.2.b After completing welds on zinc-coated (galvanized) or epoxy-coated reinforcement, repair coating damage in accordance with requirements in 3.2.1.2.a or 3.2.1.2.b, respectively. Coat welds and steel splice members used to splice reinforcement with the same material used for repair of coating damage.

3.3—Execution

3.3.1 Preparation

3.3.1.1 When concrete is placed, reinforcement shall be free of materials deleterious to bond. Reinforcement with rust, mill scale, or a combination of both will be considered satisfactory provided the minimum nominal dimensions, nominal mass, and the minimum average height of deformations of a hand-wire-brushed test specimen are not less than the applicable ASTM specification requirements.

3.3.2 Placement

3.3.2.1 Tolerances—Place, support, and fasten reinforcement as shown on the project drawings. Do not exceed

the placing tolerances specified in ACI 117M before concrete is placed. Placing tolerances shall not reduce cover requirements except as specified in ACI 117M.

3.3.2.2 Reinforcement relocation—When necessary to move reinforcement beyond the specified placing tolerances to avoid interference with other reinforcement, conduits, or embedded items, submit the resulting arrangement of reinforcement for acceptance.

3.3.2.3 Concrete cover—Minimum concrete cover for reinforcement, except for extremely corrosive atmosphere, other severe exposures, or fire protection, shall be as indicated in Table 3.3.2.3.

For bundled bars, minimum concrete cover shall be equal to the equivalent diameter of the bundle but need not be greater than 50 mm; except the minimum cover shall not be less than specified in Table 3.3.2.3. The equivalent diameter of the bundle shall be based on a single bar of a diameter derived from the equivalent total area.

Tolerances on minimum concrete cover shall meet the requirements of ACI 117M.

3.3.2.4 Reinforcement supports—Unless otherwise permitted, use the following reinforcement supports:

3.3.2.4.a Place reinforcement supported from the ground or mud mat on precast concrete reinforcement supports.

3.3.2.4.b Place noncoated reinforcement supported from formwork on reinforcement supports made of concrete, metal, or plastic.

3.3.2.4.c Place zinc-coated (galvanized) reinforcement supported from formwork on wire-reinforcement supports that are galvanized, coated with dielectric material, or made of dielectric material.

3.3.2.4.d Reinforcement and embedded steel items used with zinc-coated (galvanized) reinforcement shall be zinc-coated (galvanized) or coated with nonmetallic materials.

3.3.2.4.e Place epoxy-coated reinforcement supported from formwork on coated wire-reinforcement supports or on reinforcement supports made of dielectric material. Use coatings or materials compatible with concrete.

3.3.2.4.f When precast reinforcement supports with embedded tie wires or dowels are used with epoxy-coated reinforcement, use wires or dowels coated with dielectric material.

3.3.2.4.g Reinforcement used as supports with epoxy-coated reinforcement shall be epoxy coated.

3.3.2.4.h In walls reinforced with epoxy-coated reinforcement, use spreader bars that are epoxy coated. Proprietary combination bar clips and spreaders used in walls with epoxy-coated reinforcement shall be made of corrosion-resistant material or coated with dielectric material.

3.3.2.4.i Fasten epoxy-coated reinforcement with tie wires coated with epoxy or other polymer.

3.3.2.5 Welded wire fabric—For slabs on grade, extend welded wire fabric to within 50 mm of the concrete edge. Lap edges and ends of fabric sheets a minimum of one mesh spacing. Unless otherwise permitted, do not extend welded wire fabric through contraction joints. Support welded wire fabric during placing of concrete to ensure required position-

Table 3.3.2.3—Minimum concrete cover for reinforcement

Minimum concrete cover for reinforcement, except for extremely corrosive atmospheres, other severe exposures, or fire protection, shall be as follows:

	Minimum cover, mm
Slabs and joists	
Top and bottom bars for dry conditions	
No. 36 bars and smaller	20
No. 43 and 57 bars	40
Formed concrete surfaces exposed to earth, water, or weather, and over or in contact with sewage and for bottoms bearing on work mat, or slabs supporting earth cover	
No. 16 bars and smaller, W31 or D31 wire and smaller	40
No. 19 through 57 bars, W45 or D45 wire	50
Beams and columns, formed	
For dry conditions	
Stirrups, spirals, and ties	40
Principal reinforcement	50
Exposed to earth, water, sewage, or weather	
Stirrups and ties	50
Principal reinforcement	60
Walls	
For dry conditions	
No. 36 bars and smaller	20
No. 43 and 57 bars	40
Formed concrete surfaces exposed to earth, water, sewage, weather, or in contact with ground	50
Footings and base slabs	
At formed surfaces and bottoms bearing on concrete work mat	50
At unformed surfaces and bottoms in contact with earth	75
Top of footings	Same as slabs
Over top of piles	50

ing in the slab. Do not place welded wire fabric on grade and subsequently raise into position in concrete.

3.3.2.6 Column dowels—Furnish and use templates for placement of column dowels unless otherwise permitted.

3.3.2.7 Splices—Make splices as indicated on the project drawings unless otherwise permitted. Mechanical splices for reinforcement not shown on the project drawings shall not be used unless accepted by the Architect/Engineer. Remove reinforcement coating in the area of the mechanical splice if so required by the splice manufacturer. After installing mechanical splices on zinc-coated (galvanized) or epoxy-coated reinforcement, repair coating damage and areas of removed coating in accordance with 3.2.1.2.a or 3.2.1.2.b. Coat exposed parts of mechanical splices used on coated bars with the same material used for repair of coating damage.

3.3.2.8 Field bending or straightening—When permitted, bend or straighten reinforcement partially embedded in concrete in accordance with the following procedures.

Reinforcing bar sizes No. 10 through No. 15 may be bent cold the first time provided reinforcing bar temperature is above 0 C. For other bar sizes, preheat reinforcing bars before bending.

Table 3.3.2.8—Minimum diameter of bend

Bar size	Minimum inside bend diameter
No. 10 through 25	6 bar diameters
No. 29, 32, and 36	8 bar diameters
No. 43 and 57	10 bar diameters

3.3.2.8.a Preheating—Apply heat by any method that does not harm the reinforcing bar material or cause damage to the concrete. Preheat a length of reinforcing bar equal to at least five bar diameters in each direction from the center of the bend but do not extend preheating below the surface of the concrete. Do not allow the temperature of the reinforcing bar at the concrete interface to exceed 250 C.

The preheat temperature of the reinforcing bar shall be between 600 to 650 C.

Maintain the preheat temperature until bending or straightening is complete.

Measure the preheat temperature by temperature measurement crayons, contact pyrometer, or other acceptable methods.

Do not artificially cool heated reinforcing bars until the temperature of the bar is less than 300 C.

3.3.2.8.b Bend diameters—Minimum inside bend diameters shall conform to the requirements of Table 3.3.2.8 unless otherwise permitted. In addition, beginning of the bend shall not be closer to the concrete surface than the minimum diameter of bend.

3.3.2.8.c Repair of bar coatings—After field bending or straightening zinc-coated (galvanized) or epoxy-coated reinforcing bars, repair coating damage in accordance with 3.2.1.2.a or 3.2.1.2.b.

3.3.2.9 Field cutting of reinforcement—Reinforcement shall not be cut in the field except when specifically permitted. Do not flame cut epoxy-coated reinforcement.

3.3.2.9.a When zinc-coated (galvanized) reinforcing bars are cut in the field, coat the ends of the bars with a zinc-rich formulation used in accordance with the manufacturer’s recommendations, and repair any coating damage in accordance with 3.2.1.2.a.

3.3.2.9.b When epoxy-coated reinforcing bars are cut in the field, coat the ends of the bars with the same material used for repair of coating damage, and repair any coating damage in accordance with 3.2.1.2.b.

3.3.2.10 Reinforcement through expansion joint—Do not continue reinforcement or other embedded metal items bonded to concrete through expansion joints. Dowels bonded on only one side of a joint and waterstops shall extend through the joint.

SECTION 4—CONCRETE MIXTURES

4.1—General

4.1.1 Description—This section covers the requirements for materials, proportioning, production, and delivery of concrete.

4.1.2 Submittals

4.1.2.1 Mixture proportions—Submit concrete mixture proportions and characteristics.

4.1.2.2 Mixture proportion data—Submit field test records used to establish the required average strength in accordance with 4.2.3.3—Required average compressive strength. Submit for acceptance test data used to establish the average compressive strength of the mixture in accordance with 4.2.3.4—Documentation of required average compressive strength.

4.1.2.3 Concrete materials—Submit the following information for concrete materials, along with evidence demonstrating compliance with 4.2.1—Materials:

- For aggregates: types, pit or quarry locations, producers' names, gradings, specific gravities, and evidence not more than 90 days old demonstrating compliance with 4.2.1—Materials;
- For admixtures: types, brand names, producers, manufacturer's technical data sheets, and certification data; and
- For water and ice: source of supply.

4.1.2.4 Field test data basis—When field test records are used as the basis for selecting proportions for a concrete mixture, submit data on materials and mixture proportions with supporting test results confirming conformance with specified requirements.

4.1.2.5 Mixture proportion adjustments—Submit any adjustments to mixture proportions or changes in materials, along with supporting documentation, made during the course of the Work.

4.1.2.6 Floor concrete—Submit evaluations and test results verifying adequacy of concrete to be placed in floors when the cementitious materials content is less than the minimum specified in Table 4.2.2.1.

4.1.2.7 Calcium chloride—When calcium chloride is desired, submit a request including data demonstrating compliance with 4.2.2.5—Admixtures.

4.1.2.8 Volumetric batching—When it is desired to produce concrete by the volumetric batching method, submit request along with description of proposed method.

4.1.2.9 Time of discharge—When it is desired to exceed time for discharge of concrete required by ASTM C 94/C 94M, submit a request along with a description of the precautions to be taken.

4.1.3 Quality control

4.1.3.1 Maintain records verifying materials used are of the specified and accepted types and sizes and are in conformance with the requirements of 4.2.1—Materials.

4.1.3.2 Ensure that production and delivery of concrete conform to the requirements of 4.3.1—Measuring, batching, and mixing and 4.3.2—Delivery.

4.1.3.3 Ensure that the concrete produced has the specified characteristics in the freshly mixed state and that they are maintained during transport and delivery.

4.1.4 Materials storage and handling

4.1.4.1 Cementitious materials—Store cementitious materials in dry, weathertight buildings, bins, or silos that will exclude contaminants.

4.1.4.2 Aggregates—Store and handle aggregate in a manner that will avoid segregation and prevent contamination with other materials or other sizes of aggregates. Store ag-

gregates to drain freely. Do not use aggregates that contain frozen lumps.

4.1.4.3 Water and ice—Protect mixing water and ice from contamination during storage and delivery.

4.1.4.4 Admixtures—Protect stored admixtures against contamination, evaporation, or damage. Provide agitating equipment for admixtures used in the form of suspensions or nonstable solutions to ensure thorough distribution of the ingredients. Protect liquid admixtures from freezing and from temperature changes that would affect adversely their characteristics.

4.2—Products

4.2.1 Materials

4.2.1.1 Cementitious materials—Cementitious materials shall conform to ASTM C 150 Type I or Type II.

Alternatively, use one or a combination of the following cementitious materials when specified or permitted:

4.2.1.1.a Portland cement conforming to ASTM C 150.

4.2.1.1.b Blended hydraulic cement conforming to ASTM C 595.

4.2.1.1.c Pozzolanic mineral admixture conforming to ASTM C 618. When fly ash is used, the minimum amount shall be 15% by mass of the total cementitious materials, unless otherwise specified.

4.2.1.1.d Ground granulated blast-furnace slag conforming to ASTM C 989.

4.2.1.1.e Silica fume conforming to ASTM C 1240.

Use cementitious materials that are of the same brand and type and from the same plant of manufacture as the cementitious materials used in the concrete represented by the submitted field test records or used in the trial mixtures.

4.2.1.2 Aggregates—Aggregates shall conform to ASTM C 33, unless otherwise specified. When a single size or a combination of two or more sizes of coarse aggregates are used, the final grading shall conform to the grading requirements of ASTM C 33, unless otherwise specified or permitted.

Aggregates used in concrete shall be obtained from the same sources and have the same size ranges as the aggregates used in the concrete represented by submitted historical data or used in trial mixtures.

4.2.1.3 Water and ice—Mixing water for concrete and water used to make ice shall meet the requirements of ASTM C 94/C 94M.

4.2.1.4 Admixtures—When required or permitted, admixtures shall meet the requirements of the following:

- Air-entraining admixtures—ASTM C 260;
- Chemical admixtures—ASTM C 494;
- Chemical admixtures for use in producing flowing concrete—ASTM C 1017/C 1017M; and
- Calcium chloride—ASTM D 98.

Admixtures used in concrete shall be the same as those used in the concrete represented by submitted field test records or used in trial mixtures.

4.2.1.5 Change of materials—When brand, type, size, or source of cementitious materials, aggregates, water, ice, or admixtures are proposed to be changed, new field data—or data from new trial mixtures or evidence that indicates that

Table 4.2.2.1—Minimum cementitious-materials content requirements for floors

Nominal maximum size of aggregate, mm	Minimum cementitious-materials content, kg/m ³
37.5	280
25.0	310
19.0	320
9.5	360

Note: When fly ash is used, quantity shall not be less than 15% nor more than 25% by mass of total cementitious materials.

the change will not affect adversely the relevant properties of the concrete—shall be submitted for acceptance before use in concrete.

4.2.2 Performance and design requirements

4.2.2.1 Cementitious-materials content—The cementitious-materials content shall be adequate for concrete to satisfy the specified requirements for strength, water-cementitious materials ratio, and finishing ability.

For concrete used in floors, cementitious-materials content shall not be less than indicated in **Table 4.2.2.1** unless otherwise accepted. Acceptance of a lower cementitious-materials content will be contingent upon verification that concrete mixtures with a lower cementitious-materials content will meet the specified strength requirements and will produce concrete with equal finish quality, appearance, durability, and surface hardness.

When a history of finishing quality is not available, evaluate the proposed mixture by placing concrete in a slab at the project site using project materials, equipment, and personnel.

The slab shall be at least 2.5 x 2.5 m and have an acceptable thickness. Slump shall not exceed the specified slump. Submit evaluation results for acceptance.

4.2.2.2 Slump—Unless otherwise specified or permitted, concrete shall have, at the point of delivery, a slump of 4 in. Determine the slump by ASTM C 143/C 143M. Slump tolerances shall meet the requirements of ACI 117M.

When use of a Type I or II plasticizing admixture conforming to ASTM C 1017/C 1017M or when a Type F or G high-range water-reducing admixture conforming to ASTM C 494 is permitted to increase the slump of concrete, concrete shall have a slump of 50 to 100 mm before the admixture is added and a maximum slump of 200 mm at the point of delivery after the admixture is added, unless otherwise specified.

4.2.2.3 Size of coarse aggregate—Except when otherwise specified or permitted, nominal maximum size of coarse aggregate shall not exceed three-fourths of the minimum clear spacing between reinforcing bars, one-fifth of the narrowest dimension between sides of forms, or one-third of the thickness of slabs or toppings.

4.2.2.4 Air content—Unless otherwise specified, concrete shall be air-entrained. Unless otherwise specified, air content at the point of delivery shall conform to the requirements of **Table 4.2.2.4** for severe exposure.

For specified compressive strengths above 35 MPa, the air contents indicated in **Table 4.2.2.4** may be reduced by 1%.

Table 4.2.2.4—Air content* of concrete for various sizes of coarse aggregate

Nominal maximum size of aggregate, mm	Air content,† percent		
	Severe exposure	Moderate exposure	Mild exposure
Less than 9.5	9	7	5
9.5	7.5	6	4.5
12.5	7	5.5	4
19.0	6	5	3.5
25.0	6	4.5	3
37.5	5.5	4.5	2.5
50	5	4	2
75	4.5	3.5	1.5
150	4	3	1

*Measured in accordance with ASTM C 231, C 173, or C 138.

†Air-content tolerance is ±1-1/2%.

Measure air content in accordance with either ASTM C 231, C 173 or C 138.

4.2.2.5 Admixtures—When admixtures are specified in Contract Documents for particular parts of the Work, use the types specified.

Use of calcium chloride or other admixtures containing chloride ions shall be subject to the limitations in 4.2.2.6—Chloride-ion concentration.

When accepted, add calcium chloride into the concrete mixture in solution form only.

4.2.2.6 Chloride-ion concentration—Unless otherwise specified, maximum water-soluble chloride-ion concentrations in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall not exceed the limits of **Table 4.2.2.6**. When testing is performed to determine water-soluble chloride-ion content, test procedures shall conform to ASTM C 1218/C 1218M.

The type of member described in **Table 4.2.2.6** shall apply to the Work as indicated in the Contract Documents.

4.2.2.7 Concrete temperature—When the average of the highest and lowest temperature during the period from midnight to midnight is expected to drop below 4 C for more than three successive days, deliver concrete to meet the following minimum temperatures immediately after placement:

- 13 C for sections less than 300 mm in the least dimension;
- 10 C for sections 300 to 900 mm in the least dimension;
- 7 C for sections 900 to 1800 mm in the least dimension;
- 4 C for sections greater than 1800 mm in the least dimension.

The temperature of concrete as placed shall not exceed these values by more than 11 C.

These minimum requirements may be terminated when temperatures above 10 C occur during more than half of any 24 hr duration.

Unless otherwise specified or permitted, the temperature of concrete as delivered shall not exceed 32 C.

4.2.2.8 Strength and water-cementitious materials ratio—The compressive strength and, when required, the

Table 4.2.2.6—Maximum allowable chloride-ion content

Type of member	Maximum water-soluble chloride ion (Cl ⁻) content in concrete, percent by mass of cement
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

water-cement or water-cementitious materials ratio of the concrete for each portion of the work shall be as specified in the Contract Documents.

4.2.2.8.a When required for concrete exposed to deicing chemicals, the maximum mass of fly ash, natural pozzolans, silica fume, or ground granulated blast-furnace slag that is included in the concrete shall not exceed the percentages of the total mass of cementitious materials given in Table 4.2.2.8.

4.2.2.8.b Unless otherwise specified, base strength requirements on a 28-day compressive strength determined on 150 x 300 mm cylindrical specimens made and tested in accordance with ASTM C 31/C 31M and C 39/C 39M, respectively.

4.2.3 Proportioning

4.2.3.1 Proportion concrete to conform with 4.2.2—Performance and design requirements, to provide workability and consistency so concrete can be worked readily into forms and around reinforcement without segregation or bleeding, and to provide an average compressive strength adequate to meet acceptance requirements of 1.6.7.1—Standard molded and cured strength specimens.

If the production facility has records of field tests performed within the past 12 months and spanning a period of not less than 60 calendar days for a class of concrete within 7 MPa of that specified for the work, calculate a standard deviation and establish the required average strength f_{cr} in accordance with 4.2.3.2 and 4.2.3.3.a. If field test records are not available, select the required average strength from Table 4.2.3.3.b.

4.2.3.2 Standard deviation

4.2.3.2.a Field test data—Field test records used to calculate standard deviation shall represent materials, quality-control procedures, and climatic conditions similar to those expected in the work. Changes in materials and proportions in concrete represented by the test records shall not have been more closely restricted than those in the proposed work. Test records shall comply with one of the following:

- Data from a single group of at least 15 consecutive compressive-strength tests with the same mixture proportions.
- Data from two groups of consecutive compressive strength tests totaling at least 30. Neither of the two groups shall consist of less than 10 tests.

4.2.3.2.b Standard deviation—Calculate the standard deviation s of the strength test records as follows:

- For a single group of consecutive test results:

Table 4.2.2.8—Requirements for concrete exposed to deicing chemicals

Cementitious materials	Maximum percent of total cementitious materials by mass*
Fly ash or other pozzolans conforming to ASTM C 618	25
Slag conforming to ASTM C 989	50
Silica fume conforming to ASTM C 1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50 [†]
Total of fly ash or other pozzolans and silica fume	35 [†]

* Total cementitious material also includes ASTM C 150, C 595, and C 845 cement. The maximum percentages above shall include:

a) Fly ash or other pozzolans present in Type IP or I(PM) blended cement, ASTM C 595;
b) Slag used in manufacture of an IS or I(SM) blended cement, ASTM C 595; and
c) Silica fume, ASTM C 1240, present in blended cement.

[†] Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10%, respectively, of the total mass of cementitious materials.

$$s = \sqrt{\frac{\sum_{i=1}^n (X_i - X)^2}{n-1}} \quad (4-1)$$

where:

s = standard deviation;

n = number of test results considered;

X = average of n test results considered; and

X_i = individual test result.

- For two groups of consecutive test results:

$$s = \left\{ \frac{[(n_1 - 1)(s_1)^2 + (n_2 - 1)(s_2)^2]}{n_1 + n_2 - 2} \right\}^{1/2} \quad (4-2)$$

where:

s = standard deviation for the two groups combined;

s_1, s_2 = standard deviations for Groups 1 and 2, respectively, calculated in accordance with Eq. (4-1); and

n_1, n_2 = number of test results in groups 1 and 2, respectively.

4.2.3.3 Required average compressive strength—Calculate the required average compressive strength f_{cr} for the specified class of concrete in accordance with one of the following:

4.2.3.3.a Use the standard deviation calculated in accordance with 4.2.3.2 to establish the required average compressive strength as follows:

$$f_{cr} = f_c + 1.34ks \quad (4-3)$$

$$f_{cr} = f_c + 2.33ks - 3.4 \text{ MPa} \quad (4-4)$$

where:

f_{cr} = required average compressive strength;

f_c = specified compressive strength;

k = factor from Table 4.2.3.3.a for increase in standard deviation if the total number of tests is less than 30; and
 s = standard deviation calculated in accordance with 4.2.3.2.

Use the larger of the two values of f_{cr} calculated in accordance with 4.2.3.3.a.

Table 4.2.3.3.a—*k*-factor for increasing standard deviation for number of tests considered

Total no. of tests considered	<i>k</i> -factor for increasing standard deviation
15	1.16
20	1.08
25	1.03
30 or more	1.00

Note: Linear interpolation for intermediate number of tests is acceptable.

4.2.3.3.b When field test records are not available to establish a standard deviation, select the required average compressive strength f_{cr} from Table 4.2.3.3.b.

4.2.3.4 *Documentation of required average compressive strength*—Documentation indicating the proposed concrete proportions will produce an average compressive strength equal to or greater than the required average compressive strength, shall consist of field strength records or trial mixture.

4.2.3.4.a *Field test data*—If field test data are available and represent a single group of at least 10 consecutive strength tests for one mixture, using the same materials, under the same conditions, and encompassing a period of not less than 60 days, verify that the average of the field test results equals or exceeds f_{cr} . Submit for acceptance the mixture proportions along with the field test data.

If the field test data represent two groups of compressive strength tests for two mixtures, plot the average strength X_1 and X_2 of each group versus the water-cementitious materials ratio of the corresponding mixture proportions and interpolate between them to establish the required mixture proportions for f_{cr} .

4.2.3.4.b *Trial mixtures*—Establish mixture proportions based on trial mixtures in accordance with the following requirements:

- Use materials and material combinations proposed for the Work.
- Determine the required average compressive strength according to 4.2.3.3.a if suitable field test data are available, or use Table 4.2.3.3.b.
- Make at least three trial mixtures complying with 4.2.2—Performance and design requirements. Each trial mixture shall have a different cementitious material content. Select water-cementitious materials ratios that will produce a range of compressive strengths encompassing the required average compressive strength f_{cr} .
- Proportion trial mixtures to produce a slump within 20 mm of the maximum specified, and for air-entrained concrete, an air content within 0.5% of the required air content indicated in Table 4.2.2.4. The temperature of the freshly mixed concrete shall be recorded and shall be within 6 C of the intended maximum temperature of the concrete as mixed and delivered.
- For each trial mixture, make and cure three compressive

Table 4.2.3.3.b—Required average compressive strength f_{cr} *

Specified strength amount f_c , MPa	Required average compressive strength f_{cr} , MPa
Less than 20	$f_c + 7.0$
20 to 35	$f_c + 8.5$
Over 35 to 70	$f_c + 10.0$
Over 70 to 100	$f_c + 12.5$

*When data are not available to establish standard deviation.

strength cylinders for each test age in accordance with ASTM C 192/C 192M. Test for compressive strength in accordance with ASTM C 39/C 39M at 28 days or at the test age specified in the Contract Documents.

- From results of these tests, plot a curve showing the relationship between water-cementitious materials ratio and compressive strength.
- From the curve of water-cementitious materials ratio versus compressive strength, select the water-cementitious materials ratio corresponding to the required average compressive strength f_{cr} . This is the maximum water-cementitious materials ratio that may be used to establish mixture proportions, unless a lower water-cementitious materials ratio is specified in 4.2.2.8—Strength and water-cementitious materials ratio.
- Establish mixture proportions so that the maximum water-cementitious materials ratio is not exceeded when slump is at the maximum specified.

4.2.3.5 *Field verification of adequacy of selected mixture proportions*—Using materials and mixture proportions accepted for use in the Work, verify that the concrete can be adequately placed using the intended placing method. Place the concrete mixture using project equipment and personnel. Verify that the slump and air content obtained at the form are acceptable. Make suitable corrections to the placing methods or to the mixture proportions, if needed. Submit any adjustments to the mixture proportions to the Architect/Engineer for review and acceptance.

4.2.3.6 *Revisions to concrete mixtures*—When 15 consecutive compressive strength test results become available from the field, calculate the actual average compressive strength and standard deviation. Calculate a revised value for the required average compressive strength f_{cr} in accordance with 4.2.3.3.a. Verify that both of the requirements of 1.6.7.1—Standard molded and cured strength specimens are met.

4.2.3.6.a When the actual average compressive strength X exceeds the revised value of f_{cr} and requirements of 1.6.7.1—Standard molded and cured strength specimens, are met, the required average compressive strength f_{cr} may be decreased if the requirements of 4.2.2 performance and design requirements are met.

4.2.3.6.b If the actual average compressive strength X is less than the revised value of f_{cr} , or if either of the two requirements in 1.6.7.1—Standard molded and cured strength specimens are not met, take immediate steps to increase average compressive strength of the concrete.

4.2.3.6.c Submit revised mixture proportions for acceptance prior to placing in the work.

4.3—Execution

4.3.1 *Measuring, batching, and mixing*—Production facilities shall produce concrete of the specified quality and conforming to the requirements of this Reference Specification.

4.3.1.1 *Ready-mixed and site-produced concrete*—Unless otherwise specified, measure, batch, and mix concrete materials and concrete in conformance with ASTM C 94/C 94M.

4.3.1.2 *Concrete produced by volumetric batching and continuous mixing*—When concrete made by volumetric batching and continuous mixing is acceptable, it shall conform to the requirements of ASTM C 685 and shall satisfy the requirements of this Reference Specification.

4.3.1.3 *Prepackaged dry materials used in concrete*—If packaged dry-combined materials are used, they shall conform to the requirements of ASTM C 387, and shall satisfy the requirements of this Reference Specification.

4.3.2 *Delivery*—Concrete shall possess the specified characteristics in the freshly mixed state at the point of placing. Transport and deliver concrete in equipment conforming to the requirements of ASTM C 94/C 94M.

4.3.2.1 *Slump adjustment*—When concrete arrives at the point of delivery with a slump below that which will result in the specified slump at the point of placement and is unsuitable for placing at that slump, the slump may be adjusted to the required value by adding water up to the amount allowed in the accepted mixture proportions unless otherwise specified by the Architect/Engineer. Addition of water shall be in accordance with ASTM C 94/C 94M. Do not exceed the specified water-cementitious materials ratio or slump. Do not add water to concrete delivered in equipment not acceptable for mixing.

After plasticizing or high-range water-reducing admixtures are added to the concrete at the site to achieve flowable concrete, do not add water to the concrete.

Measure slump and air content of air-entrained concrete after slump adjustment, to verify compliance with specified requirements.

4.3.2.2 *Time of discharge*—Time for completion of discharge shall comply with ASTM C 94/C 94M, unless otherwise permitted. When discharge is permitted after more than 90 min have elapsed since batching or after the drum has revolved 300 revolutions, verify that air content of air-entrained concrete, slump, and temperature of concrete are as specified.

SECTION 5—HANDLING, PLACING, AND CONSTRUCTING

5.1—General

5.1.1 *Description*—This section covers the production of cast-in-place structural concrete. Included are methods and procedures for obtaining quality concrete through proper handling, placing, finishing, curing, and repair of surface defects.

5.1.2 Submittals

5.1.2.1 *Submit the following data unless otherwise specified:*

a. *Field control test reports*—Maintain and submit accurate records of test and inspection reports.

b. *Conveying equipment*—Submit description of conveying equipment.

c. *Temperature measurement*—Submit proposed method of measuring concrete surface temperature changes.

d. *Repair methods*—When stains, rust, efflorescence, and surface deposits must be removed as described in 5.3.7.7, submit the proposed method of removal.

e. *Qualifications of finishers*—Submit qualifications of the finishing contractor and the finishers who will perform the Work.

5.1.2.2 *Submit the following data when required:*

a. *Drawings and data*—Submit shop drawings and data for review as required by the Contract Documents.

b. *Placement notification*—When Contract Documents require advance notification of concrete placement, submit notification at least 24 hr in advance.

c. *Preplacement requirements*—Submit, when required, request for acceptance of preplacement activities.

d. *Wet-weather placement*—When placement is scheduled during wet weather, submit, when required, request for acceptance of protection.

e. *Hot-weather placement*—When placement of concrete exceeding 32 C is desired as described in 5.3.2.1.c, submit, when required, request for placement along with proposed precautions.

f. *Matching sample finish*—When required by Contract Documents, submit sample finish as described in 5.3.3.2.

g. *Exposed-aggregate surface*—When an exposed-aggregate surface is specified and a chemical retarder is proposed to be used, submit specification and manufacturer's data for the retarder and the proposed method of using retarder.

5.1.2.3 *Submit the following data when alternatives are proposed:*

a. *Construction joints*—Submit information for acceptance of proposed location and treatment of construction joints proposed but not indicated on the project drawings.

b. *Two-course slabs*—When a bonding agent other than cement grout is proposed, submit specification and manufacturer's data for bonding agent.

c. *Underwater placement*—When underwater placement is planned, submit request for acceptance of proposed method.

d. *Contraction joints*—When contraction joints other than those indicated on the Contract Documents are proposed, submit request of location.

e. *Moisture-preserving method*—When a moisture-preserving method other than specified in 5.3.6.4.a through e is proposed, submit request of the proposed method.

f. *Coated ties*—When coated form ties described in 5.3.7.2 are proposed to preclude the requirement to patch tie holes, submit proposed coated tie description.

g. *Repair materials*—When a repair material described in 5.2.1.3—Proprietary patching materials is proposed, submit the repair material specification, manufacturer's data on the proposed patching material, and the proposed preparation and application procedure.

5.1.3 Delivery, storage, and handling

5.1.3.1 Delivery—Place concrete within the time limits required in 4.3.2.2.

5.1.3.2 Storage and handling—Store and handle products to retain original quality. Do not use products stored beyond the manufacturer's recommended shelf life.

5.2—Products

5.2.1 Materials

5.2.1.1 Curing compounds—Use curing compounds that conform to ASTM C 309 or ASTM C 1315.

5.2.1.2 Waterproof sheet materials—Use waterproof sheet materials that conform to ASTM C 171.

5.2.1.3 Proprietary patching materials—Use acceptable proprietary patching materials complying with 5.3.7.6—Repair materials other than site-mixed portland cement mortar.

5.2.1.4 Bonding grout—Use bonding grout in accordance with 5.3.7.4—Preparation of bonding grout.

5.2.1.5 Site-mixed portland cement repair mortar—Use repair mortar in accordance with 5.3.7.5—Preparation of site-mixed portland cement repair mortar.

5.2.2 Performance and design requirements

5.2.2.1 Construction joints—Make and locate construction joints that are proposed, but not indicated on the project drawings, in accordance with 2.2.2.5. Do not impair strength of the structures with construction joints.

5.3—Execution

5.3.1 Preparation

5.3.1.1 Do not place concrete until data on materials and mixture proportions are accepted.

5.3.1.2 Remove hardened concrete and foreign materials from the inner surfaces of conveying equipment.

5.3.1.3 Before placing concrete in forms, complete the following:

- Comply with formwork requirements specified in Section 2—Formwork and formwork accessories;
- Remove snow, ice, frost, water, and other foreign materials from surfaces, including reinforcement and embedded items, against which concrete will be placed;
- Comply with reinforcing steel placement requirements specified in Section 3—Reinforcement and reinforcement supports;
- Position and secure in place expansion joint materials, anchors, and other embedded items; and
- Obtain acceptance of finished preparation.

5.3.1.4 Before placing a concrete slab on grade, clean foreign materials from the subgrade and complete the following:

- Subgrade shall be well drained and of uniform load-bearing nature;
- In-place density of subgrade soils shall be uniform throughout the area and at least the minimum required by Contract Documents;
- Subgrade shall be free from frost or ice; and
- Subgrade shall be moist with no free water and no muddy or soft spots.

5.3.1.5 When high ambient temperatures necessitate protection of concrete immediately after placing or finishing, make provisions in advance of concrete placement for windbreaks, shading, fogging, sprinkling, ponding, or wet covering.

5.3.1.6 During ambient temperature conditions described in 4.2.2.7—Concrete temperature, make provisions in advance of concrete placement to maintain the temperature of the concrete as specified in Section 5.3.2.1.b. Use heating, covering, or other means adequate to maintain required temperature without overheating or drying of concrete due to concentration of heat. Do not use combustion heaters unless precautions are taken to prevent exposure of the concrete to exhaust gases containing carbon dioxide.

5.3.2 Placement of concrete

5.3.2.1 Weather considerations

5.3.2.1.a Wet weather—Do not begin to place concrete while rain, sleet, or snow is falling unless adequate protection is provided and, when required, acceptance of protection is obtained.

Do not allow rain water to increase mixing water or to damage the surface of the concrete.

5.3.2.1.b Cold weather—Concrete temperatures and ambient temperatures shall meet minimum temperature requirements of 4.2.2.7—Concrete temperature.

5.3.2.1.c Hot weather—The temperature of concrete as placed shall not exceed 32 C unless otherwise permitted. Loss of slump, flash set, or cold joints due to temperature of concrete as placed will not be acceptable. When temperature of concrete exceeds 32 C, obtain acceptance, when required, of proposed precautionary measures. When temperature of steel reinforcement, embedments, or forms is greater than 50 C, fog steel reinforcement, embedments, and forms with water immediately before placing concrete. Remove standing water before placing concrete.

5.3.2.2 Conveying—Convey concrete from mixer to the place of final deposit rapidly by methods that prevent segregation or loss of ingredients and will ensure the required quality of concrete. Do not use aluminum pipes or chutes.

5.3.2.3 Conveying equipment—Use acceptable conveying equipment of a size and design that will prevent cold joints from occurring. Clean conveying equipment before each placement.

5.3.2.3.a Use belt conveyors that are horizontal or at a slope that will not cause excessive segregation or loss of ingredients. Protect concrete to minimize drying and effects of temperature rise. Use an acceptable discharge baffle or hopper at the discharge end to prevent segregation. Do not allow mortar to adhere to the return length of the belt.

5.3.2.3.b Use metal or metal lined chutes having rounded bottoms, and sloped between one vertical to two horizontal and one vertical to three horizontal. Chutes more than 6 m long and chutes not meeting slope requirements may be used, provided the discharge is into a hopper before distributing into the forms.

5.3.2.3.c Use pumping conveying equipment that permits placement rates that avoid cold joints and prevent segregation in discharge of pumped concrete.

Table 5.3.2.5—Range of characteristics, performance, and applications of internal vibrators

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Group	Diameter of head, mm	Frequency, Hz	Eccentric moment, N-mm	Average amplitude, mm	Centrifugal force, kN	Radius of action, mm	Rate of concrete placement, m ³ /hr per vibrator	Application
1	20 to 40	150 to 250	3.4 to 11.3	0.4 to 0.8	0.5 to 1.8	75 to 150	0.8 to 4	Plastic and flowing concrete in very thin members and confined places
2	30 to 60	140 to 210	9.0 to 28.3	0.5 to 1.0	1.4 to 4.0	130 to 250	2.3 to 8	Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints
3	50 to 90	130 to 200	22.6 to 79.1	0.6 to 1.3	3.1 to 8.9	180 to 360	4.6 to 15	Stiff plastic concrete (< 75 mm slump) in general construction such as walls, columns, beams, prestressed piles, and heavy slabs
4	75 to 150	120 to 180	79.1 to 282.4	0.8 to 1.5	6.7 to 17.8	300 to 520	11 to 31	Mass and structural concrete of 0 to 50 mm slump deposited in quantities up to 3 m ³ in relatively open forms of heavy construction
5	130 to 180	90 to 140	254.2 to 395	1.0 to 2.0	11.1 to 26.7	400 to 610	19 to 38	Mass concrete in gravity dams, large piers, massive walls, etc.

Column 3—While vibrator is operating in concrete.

Column 4—Computed eccentric moment ef , N-mm, where e = distance from center of gravity of eccentric to its center of rotation, mm, and f = force of gravity of eccentric, kN

Column 5—Measured or computed peak amplitude while operating in air (deviating from point of rest), $a = ew/(W + w)$, mm, where W = mass of shell and other nonmoving parts, lb, and w = mass of eccentric, kg.

Column 6—Computed centrifugal force of vibrator, $F = 4^{-2}n^2ew/g$, kN, where n = frequency of vibrator while operating in concrete, cycles/sec, and g = acceleration due to gravity, 9806 Nm/s².

Column 7—Radius over which concrete is fully consolidated.

Column 8—Assumes insertion spacing is 1-1/2 times radius of action, and that vibrator operates 2/3 of time concrete is being placed.

Column 7 and 8—These ranges reflect capacity of vibrator, mixture workability, deg of consolidation desired, and other construction conditions.

5.3.2.4 Depositing—Deposit concrete continuously in one layer or in layers to have fresh concrete deposited on in-place concrete that is still plastic. Do not deposit fresh concrete on concrete that has hardened sufficiently to cause formation of seams or planes of weakness within the section, unless construction joint requirements of 5.3.2.6 are met.

Do not use concrete that has surface-dried, partially hardened, or contains foreign material.

When temporary spreaders are used in the forms, remove the spreaders as their service becomes unnecessary. Spreaders made of metal or concrete may be left in place if prior acceptance is obtained.

Do not place concrete over columns and walls until concrete in columns and walls is no longer plastic and has been in place at least 1 hr.

Do not subject concrete to any procedure that will cause segregation. Deposit concrete as near as practicable to the final position to avoid segregation.

Place concrete for beams, girders, brackets, column capitals, haunches, and drop panels at the same time as concrete for slabs.

When underwater placement is required or permitted, place concrete by an acceptable method. Deposit fresh concrete so concrete enters the mass of the previously placed concrete from within, displacing water with a minimum disturbance to the surface of concrete.

5.3.2.5 Consolidating—Consolidate concrete by vibration.

Thoroughly work concrete around reinforcement and embedded items and into corners of forms, eliminating air and stone pockets that may cause honeycombing, pitting, or planes

of weakness. Use internal vibrators of the largest size and power that can properly be used in the Work as described in Table 5.3.2.5. Workers shall be experienced in use of the vibrators. Do not use vibrators to move concrete within the forms.

5.3.2.6 Construction joints and other bonded joints—Locate construction joints as indicated on the project drawings or as accepted in accordance with 5.1.2.3.a. Formed construction joints shall meet requirements of 2.2.2.5. Remove laitance and thoroughly clean and dampen construction joints prior to placement of fresh concrete. When bond is required or permitted it shall be achieved by one of the following:

- Use an acceptable adhesive applied in accordance with the manufacturer's recommendations;
- Use an acceptable surface retarder in accordance with manufacturer's recommendations;
- Roughen the surface in an acceptable manner that exposes the aggregate uniformly and does not leave laitance, loosened particles of aggregate, or damaged concrete at the surface; or
- Use portland cement grout of the same proportions as the mortar in the concrete in an acceptable manner.

5.3.3 Finishing formed surfaces

5.3.3.1 General—After removal of forms, give each formed surface one or more of the finishes described in 5.3.3.2—Matching sample finish, 5.3.3.3—As-cast finishes, or 5.3.3.4—Rubbed finishes. When Contract Documents do not specify a finish, finish surfaces as required by 5.3.3.5—Unspecified finishes.

5.3.3.2 Matching sample finish—When the finish is required by the Contract Documents to match a sample panel

furnished to the Contractor, reproduce the sample finish on an area at least 9 m² in a location designated by the Architect/Engineer. Obtain acceptance before proceeding with that finish in the specified locations.

5.3.3.3 As-cast finishes—Use form-facing materials meeting the requirements of 2.2.1.1—Form-facing materials. Unless otherwise specified, produce as-cast form finishes in accordance with the following requirements:

5.3.3.3.a Rough-form finish—Patch tie holes and defects. Chip or rub off fins exceeding 12 mm in height. Leave surfaces with the texture imparted by the forms.

5.3.3.3.b Smooth-form finish—Patch tie holes and defects. Remove fins exceeding 3 mm in height.

5.3.3.3.c Architectural finishes—Produce architectural finishes including special textured finishes, exposed-aggregate finish, and aggregate transfer finish in accordance with Section 6—Architectural concrete.

5.3.3.4 Rubbed finishes—Remove forms as early as permitted by 2.3.2—Removal of forms. Produce one of the following finishes on concrete specified to have a smooth form finish:

5.3.3.4.a Smooth-rubbed finish—Remove forms as early as permitted by Section 2—Formwork and formwork accessories, and perform necessary patching. Produce finish on newly hardened concrete no later than the day following formwork removal. Wet the surface and rub it with carborundum brick or other abrasive until uniform color and texture are produced. Use no cement grout other than cement paste drawn from the concrete itself by the rubbing process.

5.3.3.4.b Grout-cleaned finish—Begin cleaning operations after contiguous surfaces to be cleaned are completed and accessible. Do not clean surfaces as work progresses. Wet the surface and apply grout consisting of one part portland cement and one and one-half parts fine sand with enough water to produce the consistency of thick paint. Add white cement as needed to match color of surrounding concrete. Scrub grout into voids, and remove excess grout. When grout whitens, rub the surface and keep the surface damp for 36 hr afterward.

5.3.3.4.c Cork-floated finish—Perform necessary repairs. Remove ties, burrs, and fins. Wet the surface and apply stiff grout of one part portland cement and one part fine sand, filling voids. Add white cement as needed to match color of surrounding concrete. Use enough water to produce a stiff consistency. Compress grout into voids by grinding the surface with a slow-speed grinder. Produce the final finish with cork float, using a swirling motion.

5.3.3.5 Unspecified finishes—When a specific finish is not specified in Contract Documents for a concrete surface, apply the following finishes:

- Rough-form finish on concrete surfaces not exposed to public view; and
- Smooth-form finish on concrete surfaces exposed to public view.

5.3.4 Finishing unformed surfaces

5.3.4.1 Placement—Place concrete at a rate that allows spreading, straightedging, and darbying or bullfloating before bleed water appears.

Strike smooth the top of walls, buttresses, horizontal offsets, and other similar unformed surfaces and float them to a texture consistent with finish of adjacent formed surface.

Finish slab surfaces in accordance with one of the finishes in 5.3.4.2—Finishes and tolerances, as designated in the Contract Documents. Use qualified flatwork finishers acceptable to the Architect/Engineer.

5.3.4.2 Finishes and tolerances

5.3.4.2.a Scratched finish—Place, consolidate, strike off, and level concrete, eliminating high spots and low spots. Roughen the surface with stiff brushes or rakes before the final set. Produce a finish that will meet conventional bull-floated tolerance requirements of ACI 117M.

5.3.4.2.b Floated finish—Place, consolidate, strike off, and level concrete, eliminating high spots and low spots. Do not work concrete further until it is ready for floating. Begin floating with a hand float, a bladed power float equipped with float shoes, or a powered disk float when the bleed water sheen has disappeared and the surface has stiffened sufficiently to permit the operation. Produce a finish that will meet conventional straightedged tolerance requirements of ACI 117M, then refloat the slab immediately to a uniform texture.

5.3.4.2.c Troweled finish—Float concrete surface, then power-trowel the surface. Hand-trowel the surface smooth and free of trowel marks. Continue hand-troweling until a ringing sound is produced as the floor is troweled. Tolerance for concrete floors shall be conventional straightedged tolerance in accordance with ACI 117M, unless otherwise specified.

5.3.4.2.d Broom or belt finish—Immediately after concrete has received a floated finish, give the concrete surface a coarse transverse scored texture by drawing a broom or burlap belt across the surface.

5.3.4.2.e Dry-shake finish—Blend metallic or mineral aggregate specified in Contract Documents with portland cement in the proportions recommended by the aggregate manufacturer, or use bagged, premixed material specified in Contract Documents as recommended by the manufacturer. Float-finish the concrete surface. Apply approximately two-thirds of the blended material required for coverage to the surface by a method that ensures even coverage without segregation. Float-finish the surface after application of the first dry-shake. Apply the remaining dry-shake material at right angles to the first application and in locations necessary to provide the specified minimum thickness. Begin final floating and finishing immediately after application of the dry-shake.

After selected material is embedded by the two floatings, complete operation with a broomed, floated, or troweled finish, as specified in the Contract Documents.

5.3.4.2.f Heavy-duty topping for two-course slabs—For heavy-duty topping mixture, use the materials and methods specified in Contract Documents. Place and consolidate concrete for the base slab, and screed concrete to the specified depth below the top of the finished surface.

Topping placed the same day as the base slab shall be placed as soon as bleed water in the base slab has disappeared and the surface will support a person without appreciable indentation.

When topping placement is deferred, brush the surface with a coarse wire broom to remove laitance and scratch the surface when concrete is plastic. Wet-cure the base slab at least 3 days. Before placing the topping, clean the base slab surface thoroughly of contaminants and loose mortar or aggregate. Dampen the surface, leaving it free of standing water.

Immediately before placing topping, scrub into the slab surface a coat of bonding grout consisting of equal parts of cement and fine sand with enough water to make a creamy mixture. Do not allow grout to set or dry before topping is placed. Bonding agents other than cement grout may be used with prior acceptance.

Spread, compact, and float the topping mixture. Check for flatness of surface and complete operation with a floated, troweled, or broom finish as specified in the Contract Documents.

5.3.4.2.g Topping for two-course slab not intended for heavy-duty service—Preparation of base slab, selection of topping material, mixing, placing, consolidating, and finishing operations shall be as specified in Section 5.3.4.2.f—Heavy-duty topping for two-course slabs, except that the aggregate need not be selected for special wear resistance.

5.3.4.2.h Nonslip finish—Where a nonslip finish is required, give the surface a broom or belt finish or a dry-shake application of crushed aluminum oxide or other abrasive particles, as specified in the Contract Documents. Rate of application shall be not less than 1.2 kg/m².

5.3.4.2.i Exposed-aggregate finish—Immediately after surface of the concrete has been leveled to meet the conventional straightedged tolerance requirements of ACI 117M and the bleed water sheen has disappeared, spread aggregate of the color and size specified in Contract Documents uniformly over the surface to provide complete coverage to a depth of one stone.

Tamp the aggregate lightly to embed aggregate in the surface. Float the surface until the embedded stone is fully coated with mortar and the surface has been finished to meet the conventional straightedged tolerance requirements of ACI 117. After the matrix has hardened sufficiently to prevent dislodgment of the aggregate, apply water carefully and brush the surface with a fine-bristled brush to expose the aggregate without dislodging it.

An acceptable chemical retarder sprayed on freshly floated concrete surface may be used to extend the working time for the exposure of aggregate.

5.3.4.2.j Nonspecified finish—When the type of finish is not specified in Contract Documents, use one of the following appropriate finishes and accompanying tolerances.

- Scratched finish. For surfaces intended to receive bonded cementitious mixtures;
- Floated finish. For walks, drives, steps, ramps, and for surfaces intended to receive waterproofing, roofing, insulation, or sand-bed terrazzo; or
- Troweled finish. For floors intended as walking surfaces,

floors in manufacturing, storage, and warehousing areas, or for reception of floor coverings.

5.3.4.3 Measuring tolerances for slabs

5.3.4.3.a Measure floor slabs for suspended floors and slabs-on-grade to verify compliance with the tolerance requirements of ACI 117M as specified in 5.3.4.2. Measure floor finish tolerances within 72 hr after slab finishing and before removal of supporting formwork or shoring.

5.3.4.3.b Unless otherwise specified in the Contract Documents for residential floors, and nonresidential floor installations 900 m² or less in total project area, measure floor finish tolerances in accordance with the “10-ft straightedge method” in ACI 117M.

5.3.4.3.c Unless otherwise specified in the Contract Documents for nonresidential floor installations exceeding 900 m² in total project area, measure floor finish tolerances in accordance with ASTM E 1155 and the F-number system in ACI 117M.

5.3.5 Sawed contraction joints—Where saw-cut joints are required or permitted, start cutting as soon as concrete has hardened sufficiently to prevent dislodgment of aggregates. Saw a continuous slot to a depth of one-fourth the thickness of the slab but not less than 25 mm. Complete sawing within 12 hr after placement. If an alternative method, timing, or depth is proposed for saw cutting, submit detailed procedure plans for review and acceptance.

5.3.6 Curing and protection

5.3.6.1 Curing—Cure concrete in accordance with 5.3.6.2 or 5.3.6.3 for a minimum of 7 days after placement. Cure high-early-strength concrete for a minimum of 3 days after placement.

Alternatively, moisture retention measures may be terminated when:

- Tests made on at least two additional cylinders kept adjacent to the structure and cured by the same methods as the structure indicate that 70% of the specified compressive strength f_c , as determined in accordance with ASTM C 39/C 39M, has been attained;
- The compressive strength of laboratory-cured cylinders, representative of the in-place concrete, exceeds 85% of the specified strength f_c , provided the temperature of the in-place concrete has been maintained at 10 C or higher during curing; or
- Strength of concrete reaches f_c as determined by accepted nondestructive test methods meeting the requirements of 2.3.4.2.

When one of the curing procedures in 5.3.6.4—Preservation of moisture, is used initially, the curing procedure may be replaced by one of the other procedures when concrete is 1 day old, provided the concrete is not permitted to become surface-dry at any time. Use a curing procedure of 5.3.6.4 that supplies additional water during the entire curing period for concrete containing silica fume and when specified in the Contract Documents.

5.3.6.2 Unformed concrete surfaces—Apply one of the procedures in 5.3.6.4—Preservation of moisture, after

completion of placement and finishing of concrete surfaces not in contact with forms.

5.3.6.3 Formed concrete surfaces—Keep absorbent wood forms wet until they are removed. After formwork removal, cure concrete by one of the methods in 5.3.6.4—Preservation of moisture.

5.3.6.4 Preservation of moisture—After placing and finishing, use one or more of the following methods to preserve moisture in concrete:

- a. Ponding, continuous fogging or continuous sprinkling;
- b. Application of mats or fabric kept continuously wet;
- c. Continuous application of steam (under 65 C);
- d. Application of sheet materials conforming to ASTM C 171;
- e. Application of a curing compound conforming to ASTM C 309 or C 1315. Apply the compound in accordance with manufacturer's recommendation as soon as water sheen has disappeared from the concrete surface and after finishing operations. The application rate shall not be less than 0.2L/m². For rough surfaces, apply curing compound in two applications at right angles to each other. The material applied in each coat shall not be less than 0.2L/m² of area. Do not use curing compound on any surface where concrete or other material will be bonded unless the curing compound will not prevent bond or unless measures are to be taken to completely remove the curing compound from areas to receive bonded applications; or
- f. Application of other accepted moisture-retaining method.

5.3.6.5 Protection—Immediately after placement, protect concrete from premature drying, excessively hot or cold temperatures, and mechanical injury. Protect concrete during the curing period such that the concrete temperature does not fall below the requirements of 4.2.2.7—Concrete temperature. Maintain the concrete protection to prevent freezing of the concrete and to ensure the necessary strength development for structural safety. Remove protection in such a manner that the maximum decrease in temperature measured at the surface of the concrete in a 24 hr period shall not exceed the following:

- 28 C for sections less than 300 mm in the least dimension;
- 22 C for sections from 300 to 900 mm in the least dimension;
- 16 C for sections 900 to 1800 mm in the least dimension; or
- 11 C for sections greater than 1800 mm in the least dimension.

Measure concrete temperature using a method acceptable to the Architect/Engineer. When the surface temperature of the concrete is within 11 C of the ambient or surrounding temperature, protection measures may be removed.

5.3.7 Repair of surface defects

5.3.7.1 General—Repair tie holes and surface defects immediately after formwork removal. Where the concrete surface will be textured by sandblasting or bush-hammering, repair surface defects before texturing.

5.3.7.2 Repair of tie holes—Plug tie holes except where stainless steel ties, noncorroding ties, or acceptably coated ties are used.

When portland cement patching mortar conforming to 5.3.7.5—Preparation of portland cement patching mortar, is used for plugging, clean and dampen tie holes before applying the mortar.

When other materials are used, apply them in accordance with manufacturer's recommendations.

5.3.7.3 Repair of surface defects other than tie holes—Outline honeycombed or otherwise defective concrete with a 12 to 20 mm deep saw cut and remove such concrete down to sound concrete. When chipping is necessary, leave chipped edges perpendicular to the surface or slightly undercut. Do not feather edges. Dampen the area to be patched, plus another 150 mm around the patch area perimeter. Prepare bonding grout according to 5.3.7.4—Preparation of bonding grout. Thoroughly brush grout into the surface.

When the bond coat begins to lose water sheen, apply patching mortar prepared in accordance with 5.3.7.5—Preparation of portland cement patching mortar, and thoroughly consolidate mortar into place. Strike off mortar, leaving the patch slightly higher than the surrounding surface to permit initial shrinkage. Leave the patch undisturbed for 1 hr before finishing. Keep the patch damp for 7 days.

5.3.7.4 Preparation of bonding grout—For bonding grout, mix approximately one part cement and one part fine sand with water to the consistency of thick cream.

5.3.7.5 Site-mixed portland cement repair mortar—Mix repair mortar using the same materials as concrete to be patched with no coarse aggregate. Do not use more than one part cement to two and one-half parts sand by damp loose volume.

For repairs in exposed concrete, make a trial batch and check color compatibility of repair material with surrounding concrete. When the repair is too dark, substitute white portland cement for a part of the gray cement to produce a color closely matching surrounding concrete.

Use a repair mortar at a stiff consistency with no more mixing water than is necessary for handling and placing. Mix the repair mortar and manipulate the mortar frequently with a trowel without adding water. Use mortar at a stiff consistency.

5.3.7.6 Repair materials other than site-mixed portland cement mortar—Acceptable repair materials other than site-mixed portland cement mortar may be used for repair. Use repair materials in accordance with manufacturer's recommendations. Materials include, but are not limited to:

5.3.7.6.a Shotcrete;

5.3.7.6.b Commercial patching products, including:

- Portland cement mortar modified with a latex bonding agent conforming to ASTM C 1059 Type II;
- Epoxy mortars and epoxy compounds that are moisture-insensitive during application and after curing, that embody an epoxy binder conforming to ASTM C 881, Type III. The type, grade, and class shall be appropriate for the application as specified in ASTM C 881;
- Shrinkage-compensating or nonshrink portland cement grout conforming to ASTM C 1107; and

- Packaged, dry concrete repair materials conforming to ASTM C 928.
- 5.3.7.7 Removal of stains, rust, efflorescence, and surface deposits**—Remove stains, rust, efflorescence, and surface deposits considered objectionable by the Architect/Engineer by acceptable methods.

SECTION 6—ARCHITECTURAL CONCRETE

6.1—General

6.1.1 Description

6.1.1.1 Scope—This section covers construction of architectural concrete as designated in Contract Documents.

6.1.1.2 Coordination—Provide coordination between this Work and work of other trades, and other concrete work on the structure. Integrate this work into the structure. Prevent damage or defects that will lessen the quality of the surface.

6.1.1.3 General requirements—Architectural concrete shall comply with the requirements of Sections 1 through 5, unless otherwise indicated in Contract Documents and in this section.

6.1.2 Submittals

6.1.2.1 Submit the following data unless otherwise specified:

a. *Drawings and data*—Submit shop drawings of forms for architectural concrete. Show jointing of facing panels; locations and details of form ties and recesses; and details of joints, anchorages, and other accessories.

6.1.2.2 Submit the following data when required:

a. *Mock-ups*—When Contract Documents require full-scale mock-ups of structural items, submit a request for acceptance of the proposed location at the project site.

b. *Special finishes*—Submit, when required, mock-ups or sample panels of aggregate transfer and other special finishes.

c. *Exposed-aggregate finishes*—Submit, when required, the proposed method of producing exposed-aggregate finishes.

6.1.2.3 Review of submittals—Do not construct forms until submittals have been accepted. Do not place concrete until submitted plans for batching, mixing, placing, and curing have been accepted.

6.1.3 Quality assurance

6.1.3.1 Concrete construction technical specialists—For architectural concrete operations listed in Project Specifications, provide a technical specialist trained or approved by the specialty item manufacturer. The specialist shall be on the project site during the first 3 days of construction operations using the specialty item and at other times required by the Project Specifications to provide technical assistance.

6.1.3.2 Preconstruction conference—A preconstruction conference shall be held for this phase of the Work. Organization and procedures shall be established and agreed to by all individuals involved with this phase of the Work.

6.1.3.3 Samples and mock-up—Make full-scale mock-ups of structural items when specified in Contract Documents. Use the same equipment, materials, and procedures that will be used in the final work. Make mock-ups at acceptable locations on the project site. Use mock-ups as samples of required quality of finished construction.

6.1.4 Product delivery, storage, and handling

6.1.4.1 Aggregates—Deliver each size of aggregate to the mixer at uniform moisture content throughout each day's concrete production.

6.1.5 Project conditions

6.1.5.1 Environmental conditions—Protect architectural concrete from damage, disfigurement, and discoloration from construction to acceptance.

6.2—Products

6.2.1 Materials

6.2.1.1 Curing water and coverings—Use curing water and coverings that will not stain the concrete.

6.2.1.2 Reinforcement supports and spacers—Use stainless steel, plastic, or plastic-coated reinforcement supports and spacers near exposed surfaces, except that plastic-coated products shall not be used near surfaces that are to be sand-blasted.

6.2.1.3 Formwork—Use formwork that is watertight.

6.2.2 Performance and design requirements

6.2.2.1 Formwork

6.2.2.1.a Design forms to produce the required finish. Limit deflection of facing materials between studs, as well as deflection of studs and walers to 0.0025 times the clear span (L/400).

6.2.2.1.b Where natural plywood form finish, grout-cleaned finish, smooth-rubbed finish, or other finish is required, form faces shall be smooth and forms shall be true to line and grade. Surfaces produced shall require only minor dressing to arrive at true surfaces. Where an as-cast finish is required, construct and install the forms so that no dressing will be required in the finishing operation to match the accepted sample.

6.2.2.1.c Where as-cast surfaces, including natural plywood form finish, are specified, ensure that the panels are orderly in arrangement, with joints planned in an acceptable relation to openings, building corners, and other architectural features.

6.2.2.1.d Where panels for as-cast surfaces are separated by recessed or emphasized joints, provide in the structural design of the forms the locations of ties within the joints so patches of tie holes will be in the recessed or emphasized joints, unless otherwise specified.

6.2.2.1.e Do not reuse forms with surface wear, tears, or defects that lessen the quality of the surface. Thoroughly clean and properly coat forms before reuse.

6.3—Execution

6.3.1 Preparation—Thoroughly clean and inspect formwork and batching, mixing, conveying, and placing equipment before use. Do not use equipment for other concrete construction during architectural concrete operations.

6.3.2 Proportioning concrete mixtures—Maintain designated colors and uniformity of color, except when not required by Contract Documents. For concrete of a specified color, use the same materials and proportions throughout. Avoid changes in quantity of portland cement per unit volume of concrete. Use only one type and one brand of cement from one mill, only one

source and one nominal maximum size of coarse aggregate, only one source of fine aggregate, and only one placing consistency. For architectural concrete with exterior exposure, use air-entrained concrete with a water-cementitious materials ratio not exceeding 0.45 by mass. Air content shall comply with Table 4.2.2.4.

6.3.3 Consolidation—Do not allow vibrators to contact formwork for exposed concrete surfaces.

Where a smooth-rubbed or similar finish is specified, work the coarse aggregate back from the forms by spading or form vibration, leaving a full surface of mortar but avoiding surface voids.

6.3.4 Formwork monitoring—During concrete placement, continuously observe formwork. If deviations from desired elevation, alignment, plumbness, or camber are observed, or if weakness develops and the falsework shows undue settlement or distortion, stop work, remove the affected construction if it is unacceptably damaged, and strengthen the falsework.

6.3.5 Formwork removal—Prevent damage to concrete from formwork removal. Do not pry against face of concrete. Use only wooden wedges to separate forms from concrete.

6.3.6 Repair of tie holes and surface defects

6.3.6.1 Repair area—Where as-cast finishes are specified, the total area requiring repair shall not exceed 0.2 m² in each 90 m² of as-cast surface. This is in addition to tie-hole patches, if Contract Documents permit ties to fall within as-cast areas.

6.3.6.2 Color match—Repairs in as-cast architectural concrete shall match color and texture of surrounding surfaces. Determine by trial the mixture of repair mortar to obtain a color match with the concrete when both repair and concrete are cured and dry. After initial set, dress surfaces of repairs manually to obtain texture matching the surrounding surfaces.

6.3.6.3 Exposed aggregate—Any finishing process intended to expose aggregate on the surface shall show aggregate faces in patched areas. The outer 25 mm of patch shall contain the same aggregates as the surrounding concrete. In aggregate transfer finish, the patching mixture shall contain the same selected colored aggregates. After patches have been allowed to cure thoroughly, expose the aggregates together with the aggregates of adjoining surfaces by the same process of mortar removal.

6.3.6.4 Curing of patches—Cure patches in architectural concrete surfaces for 7 days. Protect patches from premature drying the same as the body of the concrete.

6.3.7 Finishing—Finishes shall comply with one of the following finishes or other finishes as indicated in the Contract Documents:

6.3.7.1 Textured finishes—Use textured forms or textured form liners of plastic, wood, or sheet metal. Secure liner panels in forms by cementing or stapling. Do not permit impressions of nail heads, screw heads, or washers, to be imparted to the surface of the concrete. Seal edges of textured panels to each other or to divider strips to prevent bleeding of cement paste. Use a sealant that will not stain the concrete surface.

6.3.7.2 Aggregate transfer finishes—Produce aggregate transfer and special finishes that duplicate the mock-ups or sample panels that were prepared in advance and accepted.

6.3.7.3 Exposed-aggregate finishes—Expose aggregate by an acceptable method including blasting, bush-hammering, or a surface retarder. Provide a concrete surface that will duplicate the mock-ups or sample panels that were prepared in advance and accepted.

6.3.7.3.a Scrubbed finish—Provide a scrubbed finish on partially hardened concrete. Wet the concrete surface thoroughly and scrub with fiber or wire brushes, using water freely, until surface mortar is removed and aggregate is uniformly exposed. Then rinse with clear water. If portions of the surface have become too hard to permit uniform aggregate exposure, use dilute hydrochloric acid (1 part commercial muriatic acid diluted with 4 to 10 parts water) to remove the excess surface mortar after the concrete has been in place at least 14 days. Remove the acid from the finished surface with clean water within 15 min after application.

To facilitate aggregate exposure, cast concrete against form faces coated with a chemical retarder in accordance with the manufacturer's recommendations.

6.3.7.3.b Blast finish—Sand-blast or water-blast the concrete surface to a degree sufficient to expose aggregates. Surfaces with the same specified blast finish shall be blasted the same time after placing concrete. Use stainless steel or plastic reinforcement supports and spacers near concrete surfaces to be blasted. Protect adjacent materials and inserts during abrasive blasting operations.

Unless otherwise specified in the Project Specifications, degree of blasting shall be light and shall expose fine aggregate with occasional exposure of coarse aggregate, to produce a uniform color, and not exceed a reveal of 1.5 mm.

6.3.7.3.c Tooled finish—Dress the thoroughly cured concrete surface with electric, air, or hand tools to a uniform texture. Give the surface a hand-tooled, rough or fine-pointed, crandalled, or bush-hammered surface texture, as specified by Contract Documents.

6.3.7.3.d When blasted or tooled finishes are specified, remove surface mortar to the degree specified in Contract Documents.

6.3.7.4 Applied finishes—When finishes of stucco, cementitious coatings, or similar troweled materials are specified, prepare the surface of concrete to ensure permanent adhesion of the finish. When concrete is less than 24 hr old, roughen it with a heavy wire brush or scoring tool. When concrete is older than 24 hr, roughen the surface mechanically or by etching with acid.

After roughening, wash the surface free of dust, acid, chemical retarder, and other foreign material before final finish is applied.

SECTION 7—LIGHTWEIGHT CONCRETE

7.1—General

7.1.1 Description—This section covers requirements for structural lightweight concrete. Portions of structures to be lightweight concrete under the provisions of this section

shall be designated in Contract Documents. Lightweight concrete shall comply with the requirements of Sections 1 through 5 unless otherwise specified in this section.

7.1.2 Submittals

7.1.2.1 Review of submittals—Obtain the Architect/Engineer's acceptance of required submittals before placing concrete.

7.1.3 Product delivery, storage, and handling

7.1.3.1 Aggregate storage—Unless otherwise specified or permitted, prewet dry lightweight aggregate and leave aggregates in the stockpile after prewetting for at least 12 hr before using. Follow lightweight aggregate supplier's recommendations for storage, handling, prewetting, and draining, if applicable.

7.1.3.2 Aggregate handling—Do not allow machinery to run over lightweight aggregates.

7.2—Products

7.2.1 Aggregates—Fine and coarse lightweight aggregates for lightweight concrete shall conform to ASTM C 330.

Normalweight aggregate used in lightweight concrete shall conform to 4.2.1.2—Aggregates.

7.2.2 Performance and design requirements

7.2.2.1 Concrete exposed to weather—When specified in the Contract Documents, entrain air in lightweight concrete subject to potentially destructive exposure (other than wear or loading) including exposure to freezing and thawing, severe weather, or deicer chemicals. Use $6 \pm 2\%$ air content when the nominal maximum size of aggregate is greater than 9.5 mm. Use $7 \pm 2\%$ air content when the nominal maximum size is 9.5 mm. or less. Determine the air content by the volumetric methods of ASTM C 173. Select concrete mixture proportions for air-entrained concrete to provide the specified compressive strength f_c specified in the Contract Documents.

7.2.2.2 Floors—For troweled floors, the slump of structural lightweight concrete with 100% normalweight fine aggregate placed by pump shall not exceed 125 mm at the point of placement. For other floors, slump of lightweight concrete shall not exceed 100 mm at the point of placement.

7.2.3 Mixtures

7.2.3.1 Density—Proportion lightweight concrete mixtures to meet the specified limit on maximum air-dry density determined by ASTM C 567. Correlate air-dry density with the fresh bulk density of concrete. Use the fresh bulk density as the basis for acceptance during construction. Submit test results and correlation for review.

7.2.3.2 Proportioning—Determine the quantity of cementitious materials needed to attain the specified strength for lightweight concrete in accordance with 4.2.3—Proportioning. Relate strength to cementitious materials content of the concrete. Do not use water-cementitious materials ratio.

7.2.4 Batching and mixing

7.2.4.1 Procedure—When the procedure recommended by the concrete aggregate producer is at variance with this Reference Specification, submit producers' recommendations to the Architect/Engineer for acceptance.

7.2.4.2 Low-absorption aggregate—Batch and mix aggregate that has been shown to absorb less than 2% water by mass during the first hour after inundation as required by

4.3.1—Measuring, batching, mixing, and delivery. Test aggregate for water absorption with the minimum moisture content likely to occur on the project. Predampening may be used to achieve this condition.

7.2.4.3 High-absorption aggregate—Batch and mix concrete made with lightweight aggregates absorbing 2% or more water by mass as follows:

7.2.4.3.a First add aggregate to approximately 80% of the mixing water and mix for a minimum of 1-1/2 min in a stationary mixer or 15 revolutions at mixing speed in a transit mixer.

7.2.4.3.b Then add admixtures, cement, and the withheld portion of mixing water and complete the mixing in accordance with 4.3.1—Measuring, batching, mixing, and delivery.

7.2.4.4 Slump adjustment—Additional water or air-entraining admixture, if permitted, may be added to the mixture, if needed, to bring the mixture to the specified slump after transport. For pumped concrete, increase slump of concrete entering the pump to maintain the specified slump at point of placement, as long as the requirements of 4.3.2.1—Slump adjustment, are met.

Prewet lightweight aggregate in accordance with 7.1.3.1—Aggregate storage, unless otherwise specified. For pumped concrete, prewetting shall be sufficient to ensure that slump loss through the pump line does not exceed 100 mm

7.3—Execution

7.3.1 Consolidation—Do not vibrate lightweight concrete to the extent that large particles of aggregate float to the surface.

7.3.2 Finishing—Do not work lightweight concrete to the extent that mortar is driven down and lightweight aggregate appears at the surface.

7.3.3 Field quality control

7.3.3.1 Additional testing

7.3.3.1.a Density—Acceptance of lightweight concrete in the field will be based on fresh bulk density measured in accordance with ASTM C 567. The nominal fresh bulk density shall be that corresponding to the specified maximum air-dry density calculated from the formula for approximate air-dry density in ASTM C 567. When the nominal fresh bulk density varies by more than plus or minus 32 kg/m^3 from the required density, adjust the mixture as promptly as conditions permit to bring the density to the desired level. Do not use any batch for which fresh bulk density varies by more than plus or minus 48 kg/m^3 from the specified level.

7.3.3.1.b Air content—Determine the air content of the lightweight concrete sample for each strength test in accordance with ASTM C 173.

SECTION 8—MASS CONCRETE

8.1 General

8.1.1 Description

8.1.1.1 Scope—This section covers requirements for mass concrete as designated in Contract Documents.

8.1.1.2 General requirements—Mass concrete, either plain or reinforced, shall comply with the requirements of

Sections 1 through 5 unless otherwise specified in this section.

8.1.2 Submittals—Admixtures: When use of admixtures in mass concrete is desired, submit data on the proposed admixtures.

8.2—Products

8.2.1 Materials

8.2.1.1 Cementitious materials—Comply with [4.2.1.1](#) and the following:

8.2.1.1.a Do not use ASTM C 150 Type III cement.

8.2.1.1.b Unless otherwise specified or permitted, use moderate heat of hydration portland cement, blended hydraulic cement with moderate or low heat of hydration properties, or portland cement with fly ash, pozzolan, or ground granulated blast-furnace slag.

8.2.1.2 Admixtures

8.2.1.2.a Do not use calcium chloride or other accelerating admixtures unless specifically permitted.

8.2.1.2.b Use an acceptable retarding admixture, pre-tested with project materials under project conditions, whenever prevailing temperature conditions make it necessary to prevent cold joints due to the quantity of concrete placed, to offset the effects of high concrete temperature, to permit re-vibration of the concrete, or to reduce the maximum temperature and rate of temperature rise.

8.2.2 Performance and design requirements

8.2.2.1 Cement content—Use the minimum cement content required to attain the specified compressive strength f_c , desired durability, and specified properties required in [4.2.2](#)—Performance and design requirements.

8.2.2.2 Slump—Unless otherwise permitted or specified, the slump of mass concrete shall conform to the following:

- For plain mass concrete, a slump of 75 mm; and
- For reinforced mass concrete, the requirements of [4.2.2.2](#)—Slump.

8.3—Execution

8.3.1 Placement

8.3.1.1 Placing temperatures—Unless otherwise permitted or specified, the temperature of concrete when deposited at the point of placement shall not exceed 21 C, or be less than 2 C. Concrete placed in cold weather shall meet the requirements of [4.2.2.7](#)—Concrete temperature.

8.3.1.2 Slump—Slump of the concrete when placed shall meet the tolerances of ACI 117M.

8.3.1.3 Consolidation—Place concrete in layers not more than 450 mm thick. Extend vibrator heads into the previously placed layer of plastic concrete.

8.3.2 Curing and protection

8.3.2.1 Preservation of moisture

8.3.2.1.a Cure mass concrete for the minimum curing period specified in [5.3.6](#)—Curing and protection, unless Contract Documents require longer curing.

8.3.2.1.b When a specific curing method is not specified in the Contract Documents, preserve the moisture either by maintaining the forms in place or, for surfaces not in

contact with forms, by applying one of the procedures specified in [5.3.6.4](#)—Preservation of moisture.

8.3.2.2 Cold weather concrete placement—Protect the concrete from freezing and moisture loss for the required curing period in accordance with [5.3.6.1](#)—General curing and protection. Do not use steam or other curing methods that will add heat to the concrete.

8.3.2.3 Hot-weather concrete placement—Keep forms and exposed concrete continuously wet during the curing period whenever the surrounding air temperature is above 32 C.

8.3.2.4 Control of concrete surface temperature—Unless otherwise specified, cool the concrete gradually so that the drop in concrete surface temperature during and at the conclusion of the specified curing period does not exceed 11 C in any 24 hr period.

SECTION 9—PRESTRESSED CONCRETE

9.1—General

9.1.1 Description—This section covers requirements for site-cast, post-tensioned, prestressed structural members. Prestressed concrete shall comply with the requirements in [Section 1](#) through [5](#) unless otherwise specified.

9.1.2 Submittals

9.1.2.1 Drawings—Submit shop drawings of prestressed concrete construction and provide the following information in addition to that required by [Section 2](#)—Formwork and accessories, and [Section 3](#)—Reinforcement and reinforcement supports:

- Tendon support heights and chair sizes;
- The location of tendons and sheathing throughout their length;
- Size, details, location, materials, and stress grade (where applicable) for tendons and accessories, including anchorage device details;
- Jack clearances, jacking procedures, stressing sequence, initial tensioning forces, gage pressures, and tendon elongation; and
- Details of reinforcing steel to prevent bursting and spalling.

9.1.2.2 Preliminary data—Submit the following information:

- Typical stress-strain curve of the prestressing steel;
- Results of tests for ultimate strength, yield strength, elongation, and composition for materials not produced in accordance with an ASTM specification; and
- Values of wobble and curvature friction coefficients, anchorage set data, and, when required by Contract Documents, test data substantiating the expected coefficients and anchorage set.

9.1.2.3 Field data—Before installation, submit the following information on actual materials to be used:

- Stress-strain curve for a sample representing the production lot from which the prestressing tendons will be taken;
- Certified mill test reports for the tendons; and
- Results of tests required in [9.1.3.1](#)—Testing, including demonstration of compliance with [9.2.1.5](#) through [9.2.1.7](#).

9.1.3 Quality control

9.1.3.1 Testing—Test materials in accordance with the following requirements. Include in the report a detailed description of test procedures and apparatus, as well as test results:

9.1.3.1.a Test assembly—Test, in accordance with 9.1.3.1.b, two samples of each tendon size at least 3 m in length and complete with standard production-quality anchorages. For unbonded tendons, test a third sample in accordance with 9.1.3.1.c.

9.1.3.1.b Static test—Test prestressing steel sample in accordance with the appropriate ASTM Specification of 9.2.1.1.a. Test tendon assembly with a method that will allow accurate determination of yield strength, ultimate strength, and elongation of the specimen to ensure compliance with 9.2.1.5—Anchorages for bonded tendons, or 9.2.1.6—Anchorages for unbonded tendons, and 9.2.1.7—Couplings.

9.1.3.1.c Cyclic test for unbonded tendons—When required by the Contract Documents, perform a cyclic test on a representative tendon assembly that shall withstand without failure 500,000 cycles from 60 to 66% and back to 60% of its guaranteed minimum ultimate strength. A prototype tendon assembly may be used provided the assembly has not less than 10% of the full-sized tendon strength. Test single element tendons using one strand, bar, or wire as a complete tendon assembly. Systems using multiple strands, wires, or bars may be tested using a prototype tendon with sufficient number of elements to duplicate the behavior of a full-sized tendon.

9.1.3.1.d Grout testing—Test grout for strength and shrinkage in accordance with ASTM C 1107.

9.1.3.2 Tolerances—Comply with the following tolerances:

9.1.3.2.a Bearing surface between anchorage and concrete shall be concentric with the tendons and perpendicular within plus or minus 1 deg to the direction of the tendon at the anchorage.

9.1.3.2.b Place tendons, sheathing, and anchorages within the tolerances of ACI 117M for reinforcement placement, distance between reinforcement, and concrete cover. These tolerances apply separately to both vertical and horizontal dimensions and may be different for each direction except that in slabs the horizontal tolerance shall not exceed 25 mm in 4.5 m of tendon length.

9.1.4 Product delivery, handling, and storage—Deliver, handle, and store materials in a manner that prevents mechanical damage and corrosion. Store cement and premixed grout to prevent bag set. Use cement stored at the project site for grouting only.

9.2—Products

9.2.1 Materials—Use materials that comply with the following requirements:

9.2.1.1 Prestressing tendons—Prestressing steel shall be of the type and strength required by Contract Documents and shall conform to one of the following specifications:

- ASTM A 416/A 416M;
- ASTM A 421/A 421M;
- ASTM A 722/A 722M; or
- ASTM A 779/A 779M.

Strands, wire, and bars not specifically listed in ASTM A 416/A 416M, ASTM A 421/A 421M, ASTM A 722/A 722M, or ASTM A 779/A 779M may be used provided they conform to the minimum requirements of this Reference Specification, do not have properties that make them less satisfactory than those listed in ASTM A 416/A 416M, ASTM A 421/A 421M, ASTM A 722/A 722M, or ASTM A 779/A 779M, and are acceptable to the Architect/Engineer.

Tendons shall be clean and free of excessive rust, scale, and pitting. A light oxide coating is permissible.

9.2.1.2 Coatings for unbonded tendons—Coat unbonded tendons completely with a suitable material to ensure corrosion protection. Tendon covering shall be continuous over the entire length to be unbonded, and shall prevent intrusion of cement paste or loss of coating materials during concrete placement. Protect unbonded single-strand tendons against corrosion in accordance with the PTI Specification for Unbonded Single Strand Tendons.

9.2.1.3 Sheathing for bonded tendons

9.2.1.3.a Sheathing and duct-forming materials shall not react with alkalis in the cement, shall be strong enough to retain their shape and resist damage during construction, and shall prevent the intrusion of water from the cement paste. Sheathing and duct-forming material left in place shall not cause directly or indirectly electrolytic action or deterioration. Sheathing shall be capable of transmitting forces from the grout to the surrounding concrete.

9.2.1.3.b The inside diameter of the duct shall be at least 6 mm larger than the wire, bar, or strand tendon and shall have an inside cross-sectional area at least twice that of the net area of the prestressing steel.

9.2.1.3.c Duct shall have grout holes or vents at each end and at each intended high point. Provide drain holes at each intended low point if the tendon will be subjected to freezing after placing and before grouting.

9.2.1.4 Sheathing for unbonded tendons

9.2.1.4.a Sheathing for unbonded tendons shall have sufficient strength and water resistance to prevent damage or deterioration during transportation, storage at project site, installation, and concrete placement. The sheathing shall be continuous over the unbonded length of the tendons. The sheathing shall prevent the intrusion of water from the cement paste and the escape of coating material.

9.2.1.4.b Where specified in the Contract Documents for applications in corrosive environments, the sheathing shall be connected to stressing, intermediate, and fixed anchorages to provide encapsulation of prestressing steel.

9.2.1.5 Anchorages for bonded tendons—Anchorages for bonded tendons tested in an unbonded state shall develop 90% of the minimum specified ultimate strength of the prestressing steel, without exceeding anticipated set at time of anchorage, and without slip. Anchorages that develop less than 100% of the minimum specified ultimate strength shall be used only where the bond length provided is equal to or greater than the bond length required to develop 100% of the minimum specified ultimate strength of the tendon. Provide the required bond length between the anchorage and the zone

where the full prestressing force is required under service and ultimate loads. Determine the bond length by testing a full-sized tendon. If in the unbonded state the anchorage develops 100% of the minimum specified ultimate strength, it need not be tested in the bonded state.

9.2.1.6 Anchorages for unbonded tendons—Unbonded tendon anchorages, when permitted in Contract Documents, shall develop the minimum specified ultimate strength of the prestressing steel with an amount of permanent deformation that will not decrease the expected ultimate strength of the assembly. Total strain of the tendon under ultimate load of the tendon shall be not less than 2% when measured over a minimum gage length of 3 m.

9.2.1.7 Couplings—Use couplings only where indicated on the Contract Documents or as acceptable. All couplings shall develop strength in excess of the minimum specified ultimate strength of the prestressing steel without exceeding anticipated set of either the coupling or the prestressing steel, and shall not reduce the ductility of the tendon below the minimum 2% strain specified in 9.2.1.6—Anchorages for unbonded tendons. Enclose couplings in housings that permit necessary movements during stressing. For bonded tendons, provide fittings to allow complete grouting of all the coupling components.

9.2.1.8 Sleeves and gaskets—Connect sheathing at joints with leaktight sleeves or gaskets.

9.2.2 Proportioning of concrete and grout mixtures—Comply with the following for concrete and grout mixtures:

9.2.2.1 Concrete—Proportion concrete mixtures in compliance with Section 4—Concrete mixtures.

9.2.2.2 Grout

9.2.2.2.a Grout shall consist of a mixture of cement and water unless the gross inside cross-sectional area of the sheath exceeds four times the tendon cross-sectional area, in which case fine aggregate may be added to the mixture.

9.2.2.2.b Fly ash and pozzolanic mineral admixtures may be added at a ratio not to exceed 0.30 by mass of cement. Mineral admixtures shall conform to ASTM C 618.

9.2.2.2.c Add an acceptable shrinkage-compensating or expanding admixture to produce an unrestrained expansion of the mixture less than 10% by volume of the grout.

9.2.2.2.d Do not use admixtures containing more than trace amounts of chlorides, fluorides, aluminum, zinc, or nitrates. Other admixtures may be used, provided acceptable tests or performance records show conclusively that the admixtures will have no harmful effects on the tendons, accessories, or grout.

9.2.2.2.e Use fine aggregate conforming to ASTM C 404, Size No. 2, except that all material shall pass the No. 16 sieve.

9.2.2.2.f Proportion grout to achieve a minimum compressive strength of 17 MPa at 7 days and 35 MPa at 28 days when tested in accordance with ASTM C 1107, and have a consistency that will facilitate placement and meet the requirements of 9.3.3.2—Grout.

Water content shall be the minimum necessary for proper placement, and the water-cementitious materials ratio shall not exceed 0.45 by mass.

9.2.2.2.g Mix grout in a high-speed mechanical mixer and pass the grout through a strainer into pumping equipment that has provision for recirculation. Begin pumping grout as soon after mixing as possible. Continue pumping as long as the grout retains the required consistency. Discard grout that has partially set.

9.3—Execution

9.3.1 Inspection—Conduct a visual inspection to ensure that the requirements of this Reference Specification are met. Inspection shall include, but not be limited to, the following:

- Cleanliness of material and formwork;
- Location of materials and formwork; and
- Proper tensioning of prestressing tendons.

9.3.2 Preparation

9.3.2.1 Grouting—Provide a dependable high-pressure water supply of sufficient volume before beginning grouting. Free sheathing of dirt and other foreign substances by thorough flushing with water immediately before grouting.

9.3.2.2 Tendons and concrete

9.3.2.2.a Keep tendons dry and keep water out of the conduit until flushing tendons prior to grouting. Maintain concrete around grouted tendons at a temperature of 4 C or higher for at least 3 days from the time of grouting.

9.3.2.2.b Keep sheathing for use with bonded tendons free of grease, oil, paint, and other foreign matter. A light coat of rust on the tendons is permissible, provided loose rust has been removed and the surface of the steel is not pitted.

9.3.2.2.c Keep tendons for use in unbonded construction clean and undamaged, and protect them with a permanent, continuous coating specified in 9.2.1.2—Coating for unbonded tendons.

9.3.2.2.d Where tendon extremities extend beyond the ends of the member, or where tendons are outside the concrete of the post-tensioned element, or where the structure is in or exposed to an atmosphere of salt air or high humidity, cover the exposed parts of the tendon with an additional field-applied coating of acceptable material.

9.3.2.2.e Keep end anchorages that will be permanently protected with concrete free of loose rust, grease, oil, and other foreign matter.

9.3.2.2.f Protect grout fittings and sheathing for bonded tendons from collapse and other damage. Before placing concrete, examine the sheathing and grout fittings for holes, and repair any holes located. If the tendon remains ungrouted for more than 28 days from the time of tendon placement, provide acceptable temporary corrosion protection.

9.3.3 Placement

9.3.3.1 Tendons and accessories—Place tendons and anchorages within the tolerances of 9.1.3.2—Tolerances. Firmly support tendons, sheathing, and anchorages to prevent displacement during concrete placement.

9.3.3.2 Grout

9.3.3.2.a For bonded-tendon construction, inject grout into all voids between prestressing tendons, sheathing, and anchorage fittings. Continue injection until grout of the same consistency as the grout injected flows without

the presence of air bubbles from vent openings. Close vent openings progressively in the direction of the flow. After vent openings have been closed, raise the grouting pressure to at least .34 MPa and plug the injection hole.

9.3.3.2.b In the event of a blockage or an interruption of grouting, remove grout from the duct by flushing with water.

9.3.4 *Tensioning and other operations involving tendons*

9.3.4.1 *Sequence*—Stress tendons in the sequence, at the concrete strength, and at the construction stage indicated in the Contract Documents.

9.3.4.2 *Tensioning multiple*—Element tendons—Tension simultaneously tendons composed of multiple strands, wires, or bars in a common sheath unless effects of interferences between the elements are considered potentially damaging.

9.3.4.3 *Prestressing force*—Determine prestressing force by measuring tendon elongation and checking jack pressure with a calibrated gage or dynamometer. Calibrate the gage or dynamometer within 6 months before use. Correct discrepancies that exceed 5%. Base elongation requirements on load-elongation curves for the steel used unless statistical data indicate that average values may be used. For each tendon, keep and submit a record of the measured elongations and the gage pressure or dynamometer readings.

9.3.4.4 *Prestress loss*—The total loss of prestress force in any tendon due to unreplaced broken tendon elements shall not exceed 2% of the total prestress force.

9.3.4.5 *Formwork*

9.3.4.5.a Ensure that formwork does not restrain elastic shortening, deflection, or camber resulting from application of the prestressing force, and is sufficiently rigid to prevent displacement of the tendons beyond the tolerances of 9.1.3.2. Anchor tendon supports to the formwork to maintain the tendon profile during concrete placement.

9.3.4.5.b Do not remove formwork supports until sufficient prestressing force has been applied to support the dead load, formwork, and anticipated construction loads. When a structure will be prestressed in two directions, formwork shall support the load that is redistributed by the partially completed stressing operation.

9.3.4.6 *Prevention of damage to tendons*—Do not expose tendons to mechanical damage, welding sparks, or electric ground currents. Do not conduct burning and welding operations in the vicinity of tendons without prior acceptance, except as permitted by 9.3.4.7—Trimming of tendons.

9.3.4.7 *Trimming of tendons*—Surplus lengths of tendons beyond anchorages may be removed by either rapid oxyacetylene burning, abrasive wheel, or shears unless these procedures are contrary to the recommendations of the prestressing steel manufacturer.

SECTION 10—SHRINKAGE-COMPENSATING CONCRETE

10.1—General

10.1.1 *Scope*—This section covers shrinkage-compensating concrete using expansive cement conforming to ASTM C 845, Type E-1.

10.1.2 *General requirements*—Portions of structures to be constructed using shrinkage-compensating concrete under

the provisions of this section shall be designated in the Contract Documents. Shrinkage-compensating concrete shall comply with the requirements of Sections 1 through 5 unless otherwise specified in this section.

10.1.3 *Submittals*

10.1.3.1 *Review of submittals*—Obtain the Architect/Engineer's acceptance of required submittals before placing concrete.

10.1.3.2 Submit expansion test results measured in accordance with ASTM C 878 for the concrete mixture proportions.

10.1.3.3 Submit placing sequence.

10.2—Products

10.2.1 *Materials*

10.2.1.1 *Cementitious materials*

10.2.1.1.a Unless otherwise specified, the cement shall comply with ASTM C 845, Type E-1 (K).

10.2.1.1.b When permitted, silica fume shall comply with ASTM C 1240.

10.2.1.1.c Unless otherwise specified, do not use fly ash or ground granulated blast-furnace slag.

10.2.1.2 *Admixtures*

10.2.2.1.a Do not use accelerating admixtures or admixtures containing calcium chloride unless otherwise specified or permitted.

10.2.1.2.b Do not change type, brand, or dosage rate of admixtures without evaluating the revised concrete mixture for expansion as measured in accordance with ASTM C 878, unless permitted.

10.2.2 *Performance and design requirements*—Comply with 4.2.2—Performance and design requirements, and the following:

10.2.2.1 *Minimum cement content*—Cement content shall not be less than 335 kg/m³.

10.2.2.2 *Expansion*—Unless otherwise specified, the concrete expansion shall be a minimum of 0.03% and a maximum of 0.10% as measured in accordance with ASTM C 878.

10.2.2.3 *Slump*—Unless otherwise specified or permitted, the slump shall not exceed 150 mm at the point of placement.

10.2.3 *Proportioning*—Comply with 4.2.3—Proportioning, and the following:

10.2.3.1 When laboratory trial mixtures are used, stop the mixer after the initial mixing cycle and cover the laboratory concrete mixer for 20 min, unless otherwise specified. After this time period, add water, as necessary, to produce the maximum specified slump within 20 mm. The concrete shall then be mixed for an additional 2 min.

10.2.3.2 For the proposed concrete mixture, provide laboratory test results for three expansion bars cast and tested in accordance with ASTM C 878. Record the expansion test results and submit for acceptance.

10.2.3.3 *Revisions to concrete mixtures*—When concrete mixture proportions are revised in accordance with 4.2.3.6—Revisions to concrete mixtures, evaluate the effect on expansion by performing laboratory tests on three expansion bars cast with the revised concrete mixture in accordance with ASTM C 878. Submit test results along with the revised mixture proportions.

10.2.4 Reinforcement—Use deformed bars or deformed welded wire fabric meeting the requirements of 3.2—Products, at the amounts specified in the Contract Documents.

10.2.5 Isolation-joint filler materials—Unless otherwise specified, use compressible isolation-joint filler material that does not develop a compressive stress greater than 0.17 MPa at 50% strain when tested in accordance with ASTM D 1621 or D 3575.

10.3—Execution

10.3.1 Reinforcement

10.3.1.1 Place reinforcement on supports that are rigid and spaced adequately to ensure proper positioning of the reinforcement during placement.

10.3.1.2 Unless otherwise specified, position reinforcement 50 mm from the top surface for reinforced slabs on grade.

10.3.2 Placing

10.3.2.1 Placing sequence—Sequence of concrete placements shall permit the previous placements to have at least one free edge for expansion in each direction.

10.3.2.2 Unless otherwise specified or permitted, the minimum time between casting adjoining sections shall be 72 hr.

10.3.3 Isolation joints—Provide isolation joints at junctions with columns, walls, drains or any other rigid obstruction in the structure in accordance with the Contract Documents.

10.3.4 Curing—Unless otherwise specified, wet-cure shrinkage-compensating concrete for a minimum of 7 days in accordance with [5.3.6.4 A or B](#).

Notes

NOTES TO SPECIFIERS

PREFACE TO SPECIFICATION CHECKLISTS

P1. Specification ACI 301M is intended to be used by reference or incorporation in its entirety into the Project Specifications. Individual sections, articles, or paragraphs shall not be copied into the Project Specifications, as taking them out of context may change their meaning.

P2. If sections or parts of Reference Specification ACI 301M are edited into Project Specifications or any other documents, they shall not be referred to as ACI Standards, as the Reference Specification has been altered.

P3. Building codes set minimum requirements necessary to protect the public. This Reference Specification may stipulate requirements more restrictive than the minimum. Adjustments to meet the needs of a particular project should be made by the Architect/Engineer. The Architect/Engineer should review each of the items in the Specification Checklists and include the Architect/Engineer's decision on each checklist item as a mandatory requirement in the Project Specifications.

P4. These mandatory requirements designate the specific qualities, procedures, materials, and performance criteria for which alternatives are permitted or for which provisions were not made in the Reference Specification. Exceptions to the Reference Specification shall be made in the Project Specifications, if required.

P5. A statement such as the following will serve to make Reference Specification ACI 301M a part of the Project Specifications.

Work on _____ (Project Title) shall conform to all requirements of ACI 301M-99, Specification for Structural Concrete, published by the American Concrete Institute, Farmington Hills, Michigan, except as modified by the requirements of these Contract Documents.

P6. The Specification Checklists identify Architect/Engineer choices and alternatives. The checklists identify the sections, parts, and articles of the Reference Specification and the actions required by the Architect/Engineer.

P7. The flowchart for Selection and Documentation of Concrete Mixture Proportions on p. 37 is intended as a pictorial guide demonstrating the requirements of Section 4—Concrete Mixtures. The flowchart is not a part of Reference Specification ACI 301M. It is intended to assist the Architect/Engineer in meeting the requirements of Section 4.

P8. Recommended References—The documents of the various standards-producing organizations and publications referred to in the Checklists to Specification ACI 301M are listed below with their serial designation. These references are intended to provide guidance to the Architect/Engineer and are not considered to be part of Reference Specification ACI 301M. Standards referred to in this Specification and considered to be part of Reference Specification ACI 301M can be found in Section 1.3 Reference standards and cited publications.

American Concrete Institute (ACI)
ACI 117RM Commentary on Standard Specifications for

	Tolerances for Concrete Construction and Materials
ACI 201.2R	Guide to Durable Concrete
ACI 207.2R	Effect of Restraint, Volume Change, and Reinforcement on Cracking of Mass Concrete
ACI 211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 222R	Corrosion of Metals in Concrete
ACI 223	Standard Practice for the Use of Shrinkage Compensating Concrete
ACI 225R	Guide to the Selection and Use of Hydraulic Cements
ACI 228.1R	In-Place Methods to Estimate Concrete Strength
ACI 302.1R	Guide for Concrete Floor and Slab Construction
ACI 303R	Guide to Cast-In-Place Architectural Concrete Practice
ACI 303.1	Standard Specification for Cast-In-Place Architectural Concrete
ACI 305R	Hot Weather Concreting
ACI 306.1	Standard Specification for Cold Weather Concreting
ACI 308	Standard Practice for Curing Concrete
ACI 311.1R	ACI Manual of Concrete Inspection (SP-2)
ACI 311.4R	Guide for Concrete Inspection
ACI 311.5R	Guide for Specifying Batch Plant Inspection and Field Testing of Ready-Mixed Concrete
ACI 318RM	Commentary to Building Code Requirements for Structural Concrete
ACI 347R	Guide to Formwork for Concrete
ACI CP 10	Concrete Flatwork Finisher Certification

American Society for Testing and Materials (ASTM)

ASTM C 441	Test Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
ASTM D 698	Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft ³ (600 kN-m/m ³)]
ASTM D 1557	Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort [56,000 ft-lbf/ft ³ (2,700 kN-m/m ³)]

Portland Cement Association (PCA)

PCA Design and Control of Concrete Mixtures, 13th edition

Wire Reinforcement Institute (WRI)

WRI Manual of Standard Practice

The above publications may be obtained from the following organizations (additional references can be found in Section 1.3 of the Specification):

301M-36

ACI STANDARD

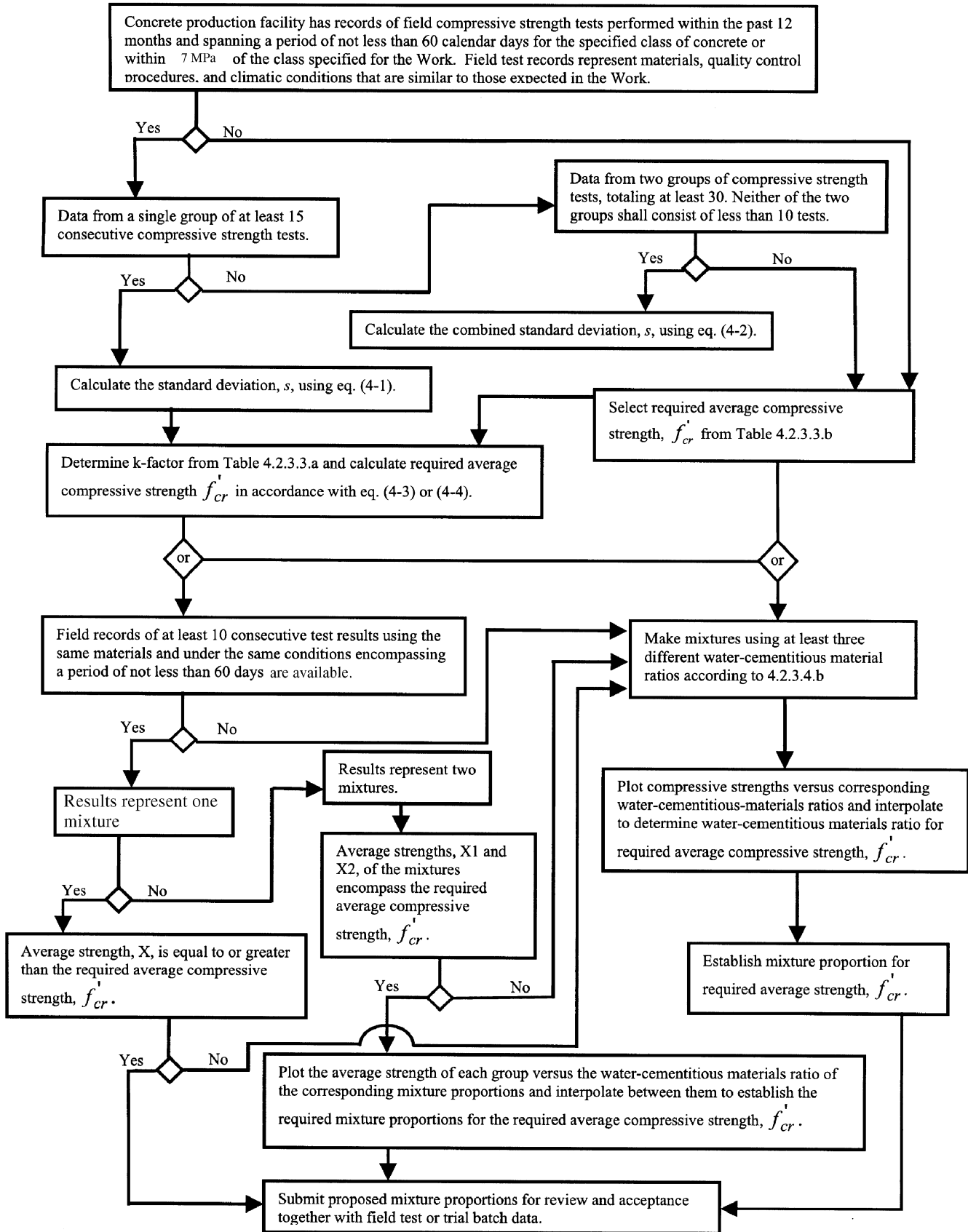
American Concrete Institute (ACI)
P.O. Box 9094
Farmington Hills, MI 48333-9094

Portland Cement Association
Old Orchard Road
Skokie, IL 60076

American Society for Testing and Materials (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428

Wire Reinforcement Institute, Inc.
301 East Sandusky Street
Findlay, OH 43840

Flow Chart for Selection of Concrete Mixture



MANDATORY REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Architect/Engineer
Reinforcement and reinforcement supports	
3.2.1.1	Specify required grades, types, and sizes of reinforcing steel.
3.3.2.7	Show splices on the project drawings.
Concrete mixtures	
4.2.2.6	Designate which portions of the structure are classified in accordance with Table 4.2.2.6 member types. Additional information on the effects of chlorides on corrosion of reinforcing steel is given in ACI 201.2R and ACI 222R. Test procedures must conform to those given in ASTM C 1218/C 1218M. An initial evaluation can be obtained by testing individual concrete ingredients for total chloride content. If total chloride-ion content, calculated on the basis of concrete proportions, exceeds that permitted in Table 4.2.2.6 , it may be necessary to test samples of hardened concrete for water-soluble chloride-ion content as described in ASTM C 1218/C 1218M. Some of the total chloride ions present in the ingredients will either be insoluble or will react with the cement during hydration and become insoluble under the test procedure described. When concretes are tested for water-soluble chloride-ion content, the tests should be made at an age of 28 to 42 days. The limits in Table 4.2.2.6 are to be applied to chlorides contributed from the concrete ingredients, not those from the environment surrounding the concrete. The water-soluble chloride-ion limits in Table 4.2.2.6 differ from the acid-soluble chloride limits recommended in ACI 201.2R and ACI 222R. For reinforced concrete that will be dry in service, a limit of 1% has been included to control total soluble chlorides. Table 4.2.2.6 includes limits of 0.15 and 0.30% for reinforced concrete that will be exposed to chlorides or will be damp in service, respectively. These water-soluble chloride-ion limits compare with the recommended acid-soluble chloride-ion limits of 0.10 and 0.15 in ACI 201.2R while 222R recommends acid-soluble chloride-ion limits of 0.08 and 0.20% for prestressed and reinforced concrete, respectively.
4.2.2.8	Indicate the specified compressive strength of concrete f_c for various portions of the Work. For most structural members, the requirements of the design will dictate the required strength. A higher compressive strength may be required for durability considerations. For floors, the specified compressive strength f_c will generally depend upon the intended use and expected wear unless durability considerations dictate higher strengths. If the floor will be exposed to abrasive wear from early construction traffic, consider requiring a minimum compressive strength at 3 days of 12.5 MPa or higher. See ACI 302.1 for guidance on compressive strengths to specify for various classes of floors.
Handling, placing, and constructing	
5.3.1.4	Specify the required in-place density of subgrade soils for slabs on grade as a percentage of the maximum laboratory density. Specify the test methods to be used such as ASTM D 698 or ASTM D 1557.
Architectural concrete	
6.3.7	Specify which of the finishes from 6.3.7.1 through 6.3.7.3 (a through d) are required. Specify any special finishes that are required, but not covered by the above.
Prestressed concrete	
9.2.1.1	Specify type and minimum ultimate tensile strength of prestressing steel.

OPTIONAL REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Architect/Engineer
General requirements	
1.6.3.2, 1.6.3.3, 1.6.4.1	Specify if other testing arrangements are required, such as Owner's testing agency establishing mixture proportions or any testing responsibilities of the Owner's testing agency that will be performed by the Contractor's testing agency.
1.6.3.2.g, 1.6.4.2.e	If accelerated testing of concrete is specified or permitted as an alternative to standard testing, specify the procedure from ASTM C 684 that is to be followed. Specify when compressive test specimens are to be tested if other than 7 and 28 days.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
1.6.4.3	Specify additional testing services desired for the work, if applicable. Note that these additional testing services are to be performed by the Owner's testing laboratory; hence, the term "will" is used in place of "shall" in 1.6.4.3. Refer to ACI 311.1R (SP-2), ACI 311.4R, and 311.5R for specific inspection items that may be appropriate. When it is necessary or desirable to know properties of concrete at the point of placement or at locations other than the delivery point, specify that concrete is to be sampled at these other locations for testing. See the discussion under Optional Requirements in Section 4.2.2.2.
1.6.5.2	Specify if nondestructive tests will be permitted to evaluate uniformity or relative in-place strength of concrete. Refer to ACI 228.1R for guidance on nondestructive test methods.
1.6.7.1	If another basis for acceptance of concrete strength level is required for accelerated strength testing, specify the basis for acceptance.
Formwork and formwork accessories	
2.1.2.1	Review the list of submittal items and specify in Contract Documents the items not to be submitted.
2.1.2.2	Review the list of submittal items and specify in Contract Documents the items to be submitted.
2.2.1.2	Indicate where walls require form ties with water-barrier plates.
2.2.2.1	Specify if calculations and drawings for formwork must be sealed by a licensed Engineer.
2.2.2.3	Specify if earth cuts will be permitted or required.
2.2.2.4	Specify more or less stringent limitations on deflection of facing materials when needed. See ACI 347R for further guidance.
2.2.2.5.b	Specify or allow alternative locations for formed construction joints when necessary to facilitate formwork removal or accelerate construction, provided that the alternative joint locations do not affect adversely the strength of the structure.
2.2.3.2	Specify if chamfer strips are not required on exterior corners of permanently exposed surfaces. Specify if bevels are required on re-entrant corners of concrete or on edges of formed concrete joints.
2.3.1.2	Specify tolerance limits required to be different than those of ACI 117M. Specify when a more or less restrictive tolerance for abrupt offset is required. Refer to ACI 347R and the Commentary to ACI 117M for further guidance.
2.3.2.5	Specify the minimum compressive strength for removal of forms supporting the mass of concrete if different than the specified compressive strength of concrete. Specify if nonload-carrying form-facing material is not permitted to be removed at an earlier age than the load-carrying portion of the formwork.
2.3.4.2	Specify if the alternative methods for evaluating concrete strength for formwork removal are permitted.
Reinforcement and reinforcement supports	
3.1.1	Specify if the submittals listed in 3.1.1.1 through 3.1.1.3 are not required to be submitted. Otherwise, they will be required to be submitted.
3.2.1.1	For forged heads, specify type of steel for reinforcing bars: <ul style="list-style-type: none"> • Low alloy steel (ASTM A 706/A 706M) • Billet steel (ASTM A 615/A 615M). For billet steel (ASTM A 615/A 615M) also specify grade • Rail steel or axle steel deformed bars (ASTM A 996/A 996M).
3.2.1.2	Specify if coated reinforcing bars are required and, if so, whether the coating is to be zinc or epoxy.
3.2.1.2.a	For zinc-coated reinforcing bars conforming to ASTM A 767/A 767M, specify the class of coating, whether galvanization is to be performed before or after fabrication, and indicate which bars require special finished bend diameters (usually smaller sizes used for stirrup and ties). Avoid mixing galvanized and nongalvanized reinforcing steel or other embedded steel that could result in galvanic cells.
3.2.1.2.b	Specify the ASTM specification to which epoxy-coated reinforcing bars are to conform.
3.2.1.4	Specify which of the three combinations will apply.
3.2.1.5	Specify plain or deformed wire and, if required, epoxy-coated wire.
3.2.1.6	Specify plain or deformed wire fabric and, if required, epoxy-coated wire fabric. Refer to WRI Manual of Standard Practice for additional guidance.
3.2.1.7	Specify if wire-reinforcement supports other than those in 3.2.1.6 are required or permitted.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
3.3.2.2	<p>Specify if bar welds are required or permitted. If required or permitted, specify any desired requirements for preparation for welding (like removal of zinc or epoxy coating) more stringent than those in AWS D1.4.</p> <p>Specify desired requirements for chemical composition of reinforcing bars more stringent than those of the referenced ASTM specifications.</p> <p>Specify special heat treatment of welded assemblies, if required. Specify supplementary requirements for welding of wire to wire, and welding of wire or welded-wire fabric to reinforcing bars or structural steels.</p>
3.3.2.3	<p>Specify special cover requirements for corrosive atmosphere, other severe exposures, or fire protection not covered in Table 3.3.2.3. Some concrete covers in Table 3.3.2.3 may exceed minimum concrete covers required by ACI 318M. Concrete covers used for design must agree with the covers specified in Table 3.3.2.3.</p>
3.3.2.4	<p>Specify if the methods of support are to be other than those indicated in items (a) through (i).</p>
3.3.2.5	<p>Specify where reinforcement may extend through contraction joints.</p>
3.3.2.8	<p>Specify if bending or straightening reinforcement partially embedded in concrete is permitted.</p>
3.3.2.9	<p>Specify if field cutting of reinforcement is permitted.</p>
Concrete mixtures	
4.2.1.1	<p>Specify if cement other than ASTM C 150 Type I or Type II is required.</p> <p>Specify if ASTM C 150 cement with ASTM C 618 pozzolanic mineral admixture, ASTM C 989 ground granulated blast-furnace slag or, ASTM C 1240 silica fume, is required. Specify the class of pozzolan or grade of slag that is required.</p> <p>Specify if ASTM C 595 blended hydraulic cement is required. Use ACI 318M and ACI 225R to determine the cementitious materials that will be acceptable for the project conditions.</p> <p>If it is suspected that concrete will be exposed to sulfates in service, evaluate the water-soluble sulfates in the soil and ground water. Use the criteria of ACI 318M, Section 4.3.1 and Table 4.3.1, to determine the cement type to use. Use any of the cements in ACI 318M, Table 4.3.1 for concrete exposed to sea water. Verify the availability of the cement specified. Do not use ASTM C 595, Type S and SA.</p> <p>Specify if less than 15% fly ash is permitted.</p> <p>In some instances, using less than 15% fly ash can increase the concrete's susceptibility to excessive expansions caused by alkali-silica reactivity (ASR). If a smaller percentage of fly ash is proposed for use, the proposed project mixture of fly ash and portland cement from the same source should be tested and compared to a control mixture using only the portland cement in accordance with ASTM C 441. The project mixture should be considered acceptable, provided the average length increase of the project mixture does not exceed that of the control mixture. For projects where expansions due to ASR may be critical, consider requiring the test comparison at some frequency during the Work, such as every three months.</p> <p>If reactive aggregates are available and may be used, specify the use of natural pozzolan, fly ash, slag, or silica fume in an amount shown to be effective in mitigating harmful expansions due to alkali-silica reactivity. Alternatively, specify a low-alkali cement be used as described in the Optional Requirements Checklist for 4.2.1.2.</p>
4.2.1.2	<p>If aggregates are to conform to a specification other than ASTM C 33 for grading, deleterious substances, or soundness, specify the other requirements.</p> <p>Specify the test for determining conformance to requirements for cleanliness, and specify grading be performed on samples obtained from the aggregates at the point of batching.</p> <p>Specify any additional requirements for aggregate such as hardness, color, mineralogical composition, texture, or shape (crushed or gravel).</p> <p>If concrete will be exposed to wetting, extended exposure to humid atmosphere, or in contact with moist ground, specify the use of aggregates that do not contain materials deleteriously reactive with alkalis in the cement, although such aggregates may be used with cement containing less than 0.60% alkalis as $(Na_2O + 0.658K_2O)$ or with a material such as natural pozzolan, fly ash, slag, or silica fume in an amount shown to be effective in preventing harmful expansion due to alkali-aggregate reaction in accordance with ASTM C 441.</p>
4.2.1.4	<p>Specify the admixtures listed in 4.2.1.4 that are required or permitted. Indicate the parts of the Work in which each type of admixture should or may be used.</p> <p>Require certification of conformance to appropriate ASTM standard.</p>

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
4.2.2.1	Specify if less than 15% or more than 25% fly ash is permitted in floors. If more than 25% is permitted, a history should be available demonstrating the finishing ability of the proposed concrete mixture.
4.2.2.2	<p>If slump is to be different than 100 mm, specify the requirement.</p> <p>It might be necessary at times to specify that the slump of concrete be determined at the point of placement rather than at the point of delivery. For example, pumped concrete is often specified to have slump measured at the end of the pumpline to preclude problems encountered with varying slump loss during pumping. This would provide for a slump higher than 100 mm at the point of delivery to obtain 100 mm slump at the end of the pumpline. Once the slump loss during pumping can be determined, acceptance or rejection of concrete based on slump can then be determined at the delivery point. For example, if a 40 mm slump loss during pumping has been established and confirmed by comparative testing, then the slump can be measured at the point of delivery to meet a 140 mm slump to meet the 100 mm slump requirement at the point of placement at the end of the pumpline.</p> <p>Specify if a plasticizing or high-range water-reducing admixture is required or permitted to produce concrete with high slumps. If so, specify the required slump if different from those indicated in 4.2.2.2.</p> <p>For floors, refer to ACI 302.1R for guidance on slumps to specify for the various classes of floors. If a plasticizing or high-range water-reducing admixture is required or permitted to obtain high-strength concretes with low water-cementitious materials ratios, such as 0.25 to 0.30, modify the requirements accordingly for the slump before adding the admixture. Confer with concrete suppliers and admixture suppliers in the area where the project is located to determine their experience and input for such high-performance concretes.</p>
4.2.2.3	If an aggregate size requirement differs from that specified by 4.2.2.3 (for example, smaller size in floor toppings), specify nominal maximum size of aggregate.
4.2.2.4	<p>Specify if concrete is not required to be air-entrained. Intentionally entrained air should not be incorporated in normalweight concrete slabs that require a dense, polished, machine-troweled surface. Refer to ACI 302.1R for further guidance.</p> <p>For air-entrained concrete for other than severe exposure, specify the type of exposure as indicated in Table 4.2.2.4. Exposure is defined as follows:</p> <p><i>Mild exposure</i>—Service in a climate where concrete will not be exposed to freezing, deicing agents, or other aggressive agents, but where air entrainment is desired for other beneficial effects, such as to improve workability or cohesion in concrete with a low cementitious materials content. To improve strength, air contents lower than those needed for durability can be used. This exposure includes indoor or outdoor service.</p> <p><i>Moderate exposure</i>—Service in a climate where freezing is expected, but where the concrete will not be continually exposed to moisture or free water for long periods before freezing and will not be exposed to deicing agents, other aggressive agents or other aggressive chemicals. Examples include exterior beams, columns, walls, girders, and slabs that are not in contact with wet soil and are located so that they will not receive direct application of deicing salts.</p> <p><i>Severe exposure</i>—Concrete that is exposed to deicing chemicals or other aggressive agents or that may become highly saturated by continual contact with moisture or free water before freezing. Examples include parking structures, pavements, bridge decks, curbs, gutters, sidewalks, canal linings, and exterior water tanks or sumps.</p> <p>Specify if a particular ASTM test method (ASTM C 231, C 138, or C 173) is required for measuring air content.</p> <p>For the same reasons as described in the Optional Requirements to 4.2.2.2, it may be necessary to specify that air content be measured at the point of placement to account for loss of air content during pumping. Once the loss of air content during pumping is established, acceptance limits at the point of placement can be determined.</p>
4.2.2.5	<p>Specify types of admixture required and indicate the parts of the Work in which each type should or may be used.</p> <p>Calcium chloride as an admixture shall not be used in concrete to be subjected to severe or very severe sulfate exposure as defined in Table 4.3.1 of ACI 318M.</p>
4.2.2.6	When epoxy- or zinc-coated bars are used, the limits in Table 4.2.2.6 may be more restrictive than necessary. Specify if higher limits are allowed. See the references given in the Mandatory Requirements Checklist for 4.2.2.6.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
4.2.2.7	These requirements have been excerpted from ACI 306.1. For projects in cold climates, such as in northern winters, or in situations where it is prudent to require the Contractor to follow specific procedures to achieve the limits of 4.2.2.7, the temperature limits for cold weather may be deleted and ACI 306.1 can be referred to in its entirety. Options within ACI 306.1 must then be exercised. Also, see the Optional Requirements Checklist for 5.3.6.1. If concrete delivered in hot weather with a temperature higher than 32 C has been used successfully in given climates or situations, the higher temperature may be specified in place of the 32 C limit.
4.2.2.8	Concrete exposed to alternating cycles of freezing and thawing in a saturated condition; deicer salts; fresh, brackish, or seawater including the area in the splash or spray zone; sulfates, and concrete that is required to have low permeability to water should be specified to have a water-cementitious materials ratio not exceeding the value in ACI 318M Tables 4.2.2 and 4.3.1, whichever is applicable. If age at test is to be other than 28 days, specify age at test. If the test specimen is to be other than a 150 x 300 mm cylindrical specimen, specify the size of the specimen. If a different test method is required, specify the test method.
4.2.2.8.a	Specify those areas that will be exposed to deicing chemicals and must comply with the limitations in Table 4.2.2.8.
4.2.3.4.b	Specify the test ages, if other than 28 days, for trial mixture proportioning.
4.3.1.1	If concrete materials are to be specified, measured, batched, or mixed other than in conformance with ASTM C 94/C 94M, specify how these procedures are to be accomplished. (For example, if volumetric batching and continuous mixing in accordance with ASTM C 685 is acceptable.)
4.3.2.1	Specify when slump adjustment by addition of water at the project site is not permitted.
4.3.2.2	If shorter or longer time for completion of discharge is required or permitted, specify maximum time.
Handling, placing, and constructing	
5.1.2.2.a	Specify if shop drawings must be submitted.
5.1.2.2.b	Specify if advance notification of concrete placement is required.
5.1.2.2.c	Specify if a request for acceptance of preplacement activities must be submitted.
5.1.2.2.d	Specify if a request for acceptance of wet-weather protection must be submitted.
5.1.2.2.e	Specify if a request for acceptance of hot-weather protection must be submitted.
5.1.2.2.f	Specify if samples finished in accordance with 5.3.3.2 must be submitted.
5.1.2.2.g	Specify if an exposed-aggregate surface is required.
5.3.2.1.c	If concrete temperatures higher than 32 C are acceptable, based on location, relative humidity, and past experience, specify a higher allowable concrete temperature in hot weather. Review the ACI 305R report for guidance to specify a higher temperature.
5.3.2.6	Specify if bond is required at construction joints.
5.3.3.2	Specify if the finish is required to match that of a sample panel to be furnished for comparison purposes. Specify the sample finish location, and the in-situ finish location.
5.3.3.3	Specify more restrictive tolerances for as-cast form finishes as needed based upon importance of surface appearance. See Optional Requirements Checklist for 2.3.1.2 for additional guidance.
5.3.3.5	Specify if finishes other than those in 5.3.3.5 are required.
5.3.4.1	Specify which of the finishes or combination of finishes in 5.3.4.2 are required. If this is not done, the finishes will be as required in 5.3.4.2.j. Stringent qualifications for the finishing contractor and finishers may be appropriate where floor serviceability is significant to the Owner and for large floor projects with specific requirements for flatness, heavy loading, frequent lift truck traffic, or automated warehouse truck traffic. For such projects, specify that the finishing contractors use qualified flatwork finishers who are skilled in the specific type of Work required and are certified ACI concrete flatwork finishers in accordance with ACI CP 10 or equivalent. Equivalent certifications should include written examinations and experience requirements similar to those stipulated in the ACI program. Additional experience requirements for the specific type of Work may also be needed.
5.3.4.2.c	Specify more restrictive tolerances if applicable. The conventional straightedged tolerance from ACI 117M applies to most general floor construction. For floors requiring tighter tolerances, such as in areas housing sensitive test or monitoring equipment, specify either "flat" or "very flat" floor tolerances from ACI 117M. Refer to the commentary for ACI 117M and ACI 302.1R for more guidance. Specify tolerances that may be more or less restrictive when applicable.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
5.3.4.2.e	For dry-shake finishes, specify the metallic or mineral aggregate, the final finishing method, and the location.
5.3.4.2.f	For heavy-duty topping for two-course slabs, specify the materials, the final finishing method, and the location.
5.3.4.2.h	For nonslip finishes, specify the location. Where abrasive particles other than crushed aluminum oxides are to be used, specify the other abrasive particles.
5.3.4.2.i	For exposed-aggregate finishes, specify the location, color, and size of aggregate. (Usually 9.5 to 16 mm)
5.3.4.3.b, 5.3.4.3.c	Alternative tolerance test methods, types of floors, and floor areas may be specified where applicable. The “3 m straightedge method of measuring tolerances” from ACI 117M applies to many small general floor construction applications. The ACI 117M F-number measuring system applies to many large specialized and general floor construction applications. For floors requiring tighter tolerances, such as in areas with frequent lift-truck traffic, automated warehouse forklifts, or housing sensitive test and monitoring equipment, specify either “flat” or “very flat” floor tolerances from ACI 117M using the F-number measuring system. When specifying the F-number measuring system for unshored floors, specify only the F_F value, not the F_L value. Note that the commentary for ACI 117M contains cautions (per ASTM E 1155) to not use the F-number measuring system within .6 m of an imbed or construction joint. Caution should also be used in specifying the F-number measuring system in floor areas that slope, unless a specific constant slope has been specified so that the F_F value is appropriate. Refer to the commentary for ACI 117M and ACI 302.1R for further guidance.
5.3.5	Specify if saw-cut contraction joints are required.
5.3.6.1	For concrete surfaces that require enhanced durability, such as high wear resistance, low permeability, or minimal cracking, a longer duration of curing may be needed than is required to meet compressive strength criteria alone. When such enhanced properties are required, minimum curing periods of 7 days for high-early-strength concrete, 14 days for concrete incorporating Type I or Type II cements, and 14 to 21 days for concrete incorporating pozzolan as one of the cementitious materials are recommended. See ACI 308 for additional guidance. Specify if a curing procedure of 5.3.6.4 that supplies additional water is required.
5.3.6.5	Requirements for rate of temperature change have been excerpted from ACI 306.1. For optional cold-weather concreting requirements, see the Optional Requirements Checklist for 4.2.2.7 and specify ACI 306.1 in its entirety, if appropriate.
5.3.7.7	If stains, rust, efflorescence, and surface deposits are to be prohibited, describe the degree to which they are unacceptable.
Architectural concrete	
6.1.1.1	Designate areas to be treated as architectural concrete. Describe special color requirements. If necessary, specify a symmetrical array of formwork panels of a specified size.
6.1.1.3	Review Sections 1 through 5 and specify requirements to be omitted or added for architectural concrete. Designate any special cementitious materials, aggregates, or admixtures required for architectural concrete.
6.1.3.1	If the importance of the Work warrants it, list operations for which a technical specialist, trained or approved by the specialty item manufacturer, is to be on the project site to provide technical assistance during the first three days of construction operations using the specialty item. Specify any other times when a technical specialist is to be on the project site to provide technical assistance.
6.1.3.3	Specify for which structural items the Contractor is to make full-scale mock-ups as samples of finished construction.
6.2.2.1.d	Specify if it is permissible for ties to be located within exposed areas of architectural concrete.
6.3.2, 6.3.7.4	Specify areas where designated colors and uniformity of color need not be maintained. Specify areas where stucco, or cementitious coating is required. If so, specify applicable requirements or refer to the applicable part of the Contract Documents for such requirements. If applicable, specify required color.
6.3.3	Specify areas where a smooth-rubbed or similar finish is required.
6.3.6.1	Specify areas where as-cast finishes are permitted or required.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
6.3.7.3.a	When acid washing or surface retarders are to be used to obtain a scrubbed finish, review ACI 303R, "Guide to Cast-in-Place Architectural Concrete Practice," and specify the recommendations and appropriate safety precautions that should be followed.
6.3.7.3.b	For a blast finish, if the degree of blasting is to be other than light, specify what degree of blasting is to be used based on the following: Brush Sufficient to dull surface sheen but not to have any reveal Light Maximum 1.5 mm aggregate exposure Medium Maximum 6 mm aggregate exposure Heavy Maximum 1/3 of the large aggregate diameter Refer to ACI 303.1 for additional guidance.
6.3.7.3.c	Where a tooled finish is specified, state whether the surface is to be given a hand-tooled, rough or fine-pointed, crandalled, or bush-hammered surface texture.
6.3.7.3.d	If blasted or tooled finishes are specified, specify the degree to which surface mortar is to be removed (removal of surface mortar only, removal of sufficient mortar to expose the surface of some coarse aggregate in relief to a specified depth, or removal with tools of sufficient material to abrade the coarse aggregate).
Lightweight concrete	
7.1.1	Designate portions of the structure to be constructed of lightweight concrete. Review Sections 1 through 5 and specify requirements to be omitted or added for lightweight concrete.
7.1.3.1	Specify if prewetting lightweight aggregate is not required.
7.2.2.1	Where lightweight concrete is subject to potentially destructive exposure other than wear or loading, specify that it be air entrained. Destructive exposures include freezing and thawing, severe weather, or deicer chemicals. Specify the required compressive strength based on the requirements of ACI 318M Section 4.2.2 and Table 4.2.2 .
7.2.3.1	For lightweight concrete, specify the maximum air-dry density.
7.2.4.4	Specify if presoaking lightweight aggregate by means other than vacuuming, ponding, or sprinkling is required.
Mass concrete	
8.1.1.1	Designate portions of the structure to be treated as either plain mass concrete or reinforced mass concrete. Whether or not concrete should be designated as mass concrete depends on many factors such as weather conditions, the volume-surface ratio, rate of hydration, degree of restraint to volume change, temperature and mass of surrounding materials, and functional and aesthetic effect of cracking. In general, heat generation should be considered when the minimum cross-sectional dimension approaches or exceeds 0.8 m or when cement contents above 360 kg/m ³ are used. The requirements for each project, however, should be evaluated on their own merits.
8.1.1.2	Review Sections 1 through 5 and specify additional requirements or any requirements to be omitted for mass concrete.
8.2.1.1	For mass concrete sections, cements such as ASTM C 150, Type II moderate heat; ASTM C 150, Type IV; ASTM C 595 (MH or LH) cements; or cement combinations with fly ash, pozzolans, or ground granulated blast-furnace slag should be used for the low heat of hydration benefits. Because low heat of hydration cementitious materials generally have lower early strengths, the compatibility of the concrete using such materials should be considered with the other work on the project. If the lower early concrete strength obtained using such cementitious materials is not acceptable, specify appropriate procedures to be used. The availability of cementitious materials should also be considered when specifying a particular cement or cementitious material combination.
8.2.1.2.a	As a general rule, accelerating admixtures should not be used in mass concrete because they contribute to early undesirable heat development. On rare occasions, such as when early formwork removal is critical, accelerating admixtures may be needed to accelerate strength development in reinforced mass concrete during winter conditions. Calcium chloride if used, should not be permitted in excess of 1% by mass of cement. The use of any accelerating admixture must be accepted by the Architect/Engineer.
8.2.2.1	When 28-day strength is not required for service conditions, a reduction in cement content can be achieved by requiring that concrete mixtures be proportioned for a strength at ages other than 28 days, such as at 56 or 90 days. Use of fly ash or other acceptable pozzolan may also reduce the required cement content. The Contract Documents should specify the use of pozzolans and later-age design strengths when acceptable.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
8.2.2.2	Specify the maximum permissible slump if it is to be other than 75 mm for plain mass concrete or that required by 4.2.2.2 for reinforced mass concrete.
8.3.1.1	If the limits on temperature of concrete when deposited are to be other than as given in 8.3.1.1, specify maximum and minimum placing temperatures.
8.3.2.1.a	A curing period of 7 days is sufficient for mass concrete proportioned for a 28-day specified strength. When concrete strength is based upon 56 or 90-day compressive strength, the curing period should be extended to a minimum of 14 days. Specify the duration of curing if longer than 7 days is required.
8.3.2.1.b	Mass concrete is best cured with water for the additional cooling benefit in warm weather. When water curing is impractical, such as when the surrounding air temperature is less than 0 C, other methods such as the use of liquid membrane-forming compounds may be used. Specify if a particular curing method is desired.
8.3.2.4	Specify additional or optional temperature controls as appropriate to minimize thermal cracking. For example, limitations on temperature differentials between the center and surface of the concrete may be desirable for large structurally reinforced placements such as large mat foundations if the entire concrete section can be cast in one continuous placement and the external restraint from adjacent concrete elements can be avoided. Complying with limitations on temperature differentials will normally require keeping concrete warm with insulation. Additional reinforcing steel may also be needed to minimize crack widths from base restraint and the higher peak concrete temperatures. See PCA publication "Design and Control of Concrete Mixtures," 13th edition, and ACI 207.2R for additional guidance.
Prestressed concrete	
9.1.1	Review Section 1 through 5 and specify additional requirements or requirements to be omitted for prestressed concrete.
9.1.2.2	If required, specify that the Contractor submit test data substantiating expected coefficients and anchorage set.
9.1.3.1.c	Specify if a cyclic test of unbonded tendons is required.
9.2.1.4.b	Indicate areas that are considered to be corrosive environments where encapsulation of the prestressing steel at stressing, intermediate, and fixed anchorages is required.
9.2.1.6	Specify if unbonded tendon anchorages are permitted.
9.2.1.7	Indicate areas where couplings may be used.
9.3.2.2.d	Indicate areas that will be exposed to an atmosphere of salt air or high humidity.
9.3.4.1	Specify the sequence, the concrete strength, and the stages at which tendons should be stressed.
Shrinkage-compensating concrete	
10.2.1.1.a	If an expansive cement other than ASTM C 845, Type E-1 (K) is acceptable or required, specify the cement type.
10.2.1.1.c	Fly ash or ground granulated blast-furnace slag will affect the expansion and should not be used without adequate testing.
10.2.1.2.a	Accelerating admixtures, specifically ones that contain calcium chloride, may reduce the expansion of the concrete and should not be permitted for use in shrinkage-compensating concrete.
10.2.1.2.b	Admixtures may have an effect on the expansion of the specific concrete mixture. Do not permit changes in admixture dosage or type without additional testing. See ACI 223 for additional information.
10.2.2.2	If different minimum and maximum limits for expansion are desired, specify the requirements. Minimum expansion needed is based on the projected shrinkage for the particular concrete mixture and the amount of reinforcement used. Consult ACI 223 for guidance.
10.2.2.3	If slump is to be different than 150 mm maximum at the point of placement, specify the requirement. Refer to Optional Requirements Checklist 4.2.2.2 for guidance on slump loss between delivery and placements points.
10.2.3.1	Due to the initial slump loss of shrinkage-compensating concrete, it is necessary to proportion the concrete mixture to consider initial slump loss. If the concrete mixture used in the Work has a delivery time longer than 20 min, specify a longer hold time to be used in the trial mixture proportioning procedure. Consult ACI 223 for guidance.
10.2.4	Specify the grade of reinforcing bar and the amounts of reinforcement required. Shrinkage-compensating concrete must always be reinforced. The reinforcement should be determined in accordance with ACI 318M. See ACI 223 for additional guidance.

OPTIONAL REQUIREMENTS CHECKLIST, continued

Section/Part/Article	Notes to Architect/Engineer
10.2.5	Specify alternative compressible isolation-joint filler material if desired.
10.3.1.2	Specify position of bars in reinforced slabs on grade if different from 50 mm from top surface.
10.3.2.2	If a longer time between casting of adjoining sections is needed, specify the time required. See ACI 223 for guidance.
10.3.4	If shrinkage-compensating concrete is cured by a method other than wet curing, the expansion will be reduced significantly. The structure or slab should be designed to compensate for this reduced expansion. See ACI 223 for guidance. If curing is to be continued for a period longer than 7 days, or if a method other than water curing is acceptable, specify the requirements in the Contract Documents.

SUBMITTALS CHECKLIST

NOTE: The items listed will be submitted by the Contractor and reviewed by the Architect/Engineer.

Notify the Contractor of acceptance or rejection after review of submittals. All submittals and responses should be retained in files for future reference during the Work. Some submittal requirements shown will apply only when optional requirements are selected and written into the Project Specifications. Once optional requirements have been selected, review the section/part/article indicated for the submittal item to see if it applies.

Section/Part/Article	Submittal items and notes to Architect/Engineer
General requirements	
1.6.3.1	Proposed testing agency.
1.6.3.2.e	Data and test documentation on materials and concrete mixtures.
1.6.3.2.f	Quality-control program of the concrete supplier.
1.6.3.2.g	Request to use accelerated testing and correlation data.
1.6.4.1.c	Test and inspection results.
1.7.1.4	Proposed repair methods, materials, and modifications to the Work.
1.7.4.2.e	Description of repair Work performed to bring strength-deficient concrete into compliance with the Contract Documents.
1.7.5.2.e	Description of repair performed to bring potentially nondurable concrete into compliance with the Contract Documents.
Formwork and formwork accessories	
2.1.2.1.a	Data on formwork facing materials if different from that specified in 2.2.1.1.
2.1.2.1.b	Data on proposed departure from location or detail of construction joints shown on the project drawings.
2.1.2.1.c	Correlation data for alternative methods of determining strength of concrete for formwork removal.
2.2.2.1.d, 2.3.2.5	Detailed plan for formwork removal at a lower compressive strength than specified.
2.1.2.1.e	Plan and procedures for installation and removal of reshoring and backshoring. See ACI 347R for guidance on items to consider.
2.1.2.1.f	Data on formwork release agent or formwork liners.
2.1.2.2.a	Shop drawings for formwork.
2.1.2.2.b	Calculations for formwork, reshoring, and backshoring.
2.1.2.2.c	Data and samples of form ties.
2.1.2.2.d	Data and samples of expansion joint materials.
2.1.2.2.e	Data and samples of waterstops.
2.2.2.5	Alternative locations and details for formed construction and contraction joints.
2.3.2.5	Detailed plan for formwork removal at a lower compressive strength than specified.
2.3.4.2	Data correlating alternative concrete strength-measuring methods for formwork removal.
Reinforcement and reinforcement supports	
3.1.1.1.a	Placing drawings showing fabrication dimensions and locations for placement of reinforcement and supports.
3.1.1.1.b	Request to use splices not shown on the project drawings.
3.1.1.1.c, 3.3.2.7	Request to use mechanical splices not shown on the project drawings.
3.1.1.1.d	Request for placement of column dowels without the use of templates.
3.1.1.1.e, 3.3.2.8	Request and procedure to field bend or straighten partially embedded reinforcement.

SUBMITTALS CHECKLIST, continued

Section/Part/Article	Submittal items and notes to Architect/Engineer
3.1.1.2.a	Description of reinforcement weld locations, weld procedures, and welder qualifications.
3.1.1.2.b	Proposed supports for coated reinforcement and uncoated reinforcement not covered in 3.3.2.4.
3.1.1.3.a, 3.3.2.2	When the Contractor finds it necessary to move reinforcement beyond the specified placing tolerances to avoid interference with other reinforcement, conduits, or embedded items, review a submittal showing the resulting arrangement of reinforcement.
3.2.2.1	Request to heat and bend reinforcement.
3.3.2.5	Request to extend welded wire fabric through contraction joints.
3.3.2.9	Request to field cut reinforcement.
Concrete mixtures	
4.1.2.1	Mixture proportions and characteristics. Check that mixture proportions conform to the requirements of 4.2.2 for cementitious-material content, yield, water-cementitious materials ratio, slump, nominal maximum size of coarse aggregate, air content, admixtures, and chloride-ion concentration, as well as compressive strength.
4.1.2.2	<p>Method and test data used to establish mixture proportions.</p> <p>Several different methods can be used to select mixture proportions to produce the necessary placeability, density, strength, and durability of the concrete.</p> <p>Field experience of concrete mixtures previously used under similar conditions provides the best assurance that the proposed concrete mixture can be used satisfactorily and will have the specified properties.</p> <p>If there is no field experience, ACI 211.1 provides guidance for selection of the initial quantities of materials based on material properties and specified concrete properties. When a field test record is not available, ACI 211.1 recommends that mixture characteristics be checked by trial batches in the laboratory or in the field.</p> <p>Blending aggregates to meet criteria for a combined grading is another proportioning method that can be used. Listed below are some of the different procedures that have been used to determine proportions of blended aggregates:</p> <ul style="list-style-type: none"> • Combined fineness modulus; • 8 to 18% retained on each of the standard sieves; • Coarseness factor chart; • 0.45 power chart. <p>When one of the above or other similar methods are used, the specific combined grading to which aggregate is to be blended, along with the tolerances for control, should be submitted. This method also requires concrete characteristics to be checked by trial batches.</p>
4.1.2.3	<p>Information on types, classes, producers' names, and plant locations for cementitious materials; types, pit or quarry locations, producers' names, gradings and properties required by ASTM C 33 for aggregates; types, brand names, and producers' names for admixtures; and source of supply for water and ice.</p> <p>Except for admixtures and water, test results confirming conformance with applicable specifications shall not be more than 90 days old. Test results for aggregate soundness, abrasion, and reactivity may be older than 90 days, but not older than 1 year, provided test results for the other properties specified in ASTM C 33 indicate that the aggregate quality has not changed.</p>
4.1.2.4	Materials, mixture proportions, and field strength-test data used for proportioning.
4.1.2.5	<p>Requests for adjustments to mixture proportions.</p> <p>Requests to adjust mixture proportions necessary for workability or consistency.</p> <p>If the Contractor desires to decrease the cementitious-materials content of the concrete mixture after having satisfied the requirements of 4.2.3.6, review a request for acceptance of the proposed revised mixture with a lower cementitious-materials content on a trial basis.</p> <p>If the Contractor finds it necessary to increase the cementitious-materials content, review a request for acceptance of the proposed revised mixture with a higher cementitious-materials content on a trial basis.</p> <p>Confirmation that adequacy of modified proportions has been verified from a set of new field test data.</p>
4.1.2.6	Evaluation and test results required in 4.2.2.1 verifying the adequacy of concrete to be placed in floors if the cement content is less than the minimum specified in Table 4.2.2.1.
4.1.2.7	Request to use calcium chloride.
4.1.2.8	Request to use the volumetric batching method.

SUBMITTALS CHECKLIST, continued

Section/Part/Article	Submittal items and notes to Architect/Engineer
4.1.2.9	Requests to exceed the ASTM C 94/C 94M required time of discharge.
4.2.1.1	Requests to use cementitious materials other than ASTM C 150 Type I or Type II.
4.2.6.3.c	Revised mixture proportions based on revised value of f_{cr} .
Handling, placing, and constructing	
5.1.2.1.a	Test and inspection records.
5.1.2.1.b	Description of conveying equipment.
5.1.2.1.c	Proposed method of measuring concrete surface temperature changes.
5.1.2.1.d	Proposed repair method for removal of stains, rust, efflorescence, and surface deposits.
5.1.2.1.e	Qualifications of finishing contractor and flatwork finishers.
5.1.2.2.a	Shop drawings of placing, handling, and constructing methods.
5.1.2.2.b	Advance notification of forthcoming placement. If required, arrange for tests and inspection to be properly coordinated.
5.1.2.2.c	Request for acceptance of preplacement activities to ensure the preplacement activities are properly inspected, if necessary.
5.1.2.2.d	Proposed wet-weather protection activities.
5.1.2.2.e	Proposed precautions for placement of concrete hotter than 32 C.
5.1.2.2.f	Sample finish.
5.1.2.2.g	Specification and manufacturer's data for chemical retarder used in producing exposed-aggregate finish along with method of use.
5.1.2.3.a	Proposed location and treatment of construction joints not shown on the project drawings. Review proposed methods for roughening the surface and the use of portland cement grout.
5.1.2.3.b	Bonding agents other than cement grout for two-course slabs.
5.1.2.3.c	Proposed method for underwater placement.
5.1.2.3.d	Proposed location of contraction joints not indicated on the project drawings.
5.1.2.3.e, 5.3.6.4	Proposed methods of curing other than those of 5.3.6.4.a through e.
5.1.2.3.f	Description of proposed coated form ties.
5.1.2.3.g, 5.2.1.3, 5.3.7.6	Specification and data and methods of use for any proposed repair material other than site-mixed portland cement mortar described in 5.3.7.5 (see 5.3.7.6). For patches in exposed concrete, exercise caution when using the materials described in 5.3.7.6, particularly with regard to both possible color changes from weathering and delamination due to differing coefficients of thermal expansion. Ensure that the material, including ASTM type or class, is appropriate for the moisture and thermal conditions of exposure.
5.3.2.1.c	Request to exceed 32 C concrete temperature, along with proposed precautionary measures.
5.3.2.6	Proposed materials and methods to prepare the concrete surface to achieve bond.
5.3.4.2.f	Request to use bonding agents other than cement grout.
5.3.5	Detailed plan for alternate saw-cutting method, such as shallow-cut and dry-cut method. See ACI 302.1R for further guidance.
5.3.6.5	Method of measuring concrete surface temperature.
Architectural concrete	
6.1.2.1.a	Shop drawings and fabricating drawings of formwork for architectural concrete. These drawings should show jointing of facing panels; locations and details of form ties and recesses; details of joints, anchorages, and other accessories; and any necessary alignment bracing. Review drawings for condition of finished surface, jointing, location of form tie holes and their treatment, types of form ties, location and details of rustication strips, leak-tightness, assembly, and removal.
6.1.2.2.a	Request for the proposed location of full-scale mock-ups at the project site.
6.1.2.2.b	Mock-ups or sample panels of aggregate transfer and other special finishes.
6.1.2.2.c	When an exposed-aggregate finish is required, review a description of the method (such as blasting, bush-hammering or use of a surface retarder) the Contractor desires to use to expose aggregate.
Lightweight concrete	
7.1.2.1	Field placement test results.
7.1.3.1	Request for alternate prewetting methods or times for lightweight aggregate.
7.2.3.1	Data correlating air-dry density to fresh bulk density.

SUBMITTALS CHECKLIST, continued

Section/Part/Article	Submittal items and notes to Architect/Engineer
7.2.4.1	Proposed batching and mixing procedure that varies from the specified requirements in Section 4—Concrete mixtures and Article 7.2.4—Batching and mixing (lightweight concrete) . Such variances would probably be as recommended by the aggregate producer and concrete supplier. If the Contractor needs additional water or air entrainment, review the request to do so.
7.2.4.4	If the Contractor needs additional water or air entrainment to bring the concrete to the specified slump, review the request and quantities to be added.
Mass concrete	
8.1.2, 8.2.1.2	If the Contractor deems it necessary to use a retarding, accelerating, or other admixture in mass concrete, review manufacturer’s data on the admixture and the Contractor’s test results on the admixture with the other project materials.
Prestressed concrete	
9.1.2.1	Shop drawings and data on: <ul style="list-style-type: none"> • Tendon location and sheathing; • Size, details, location, materials, and stress grade (where applicable) for tendons and accessories; • Jack clearances, jacking procedure, stressing sequence, initial tendon forces, gage pressures, and tendon elongation.
9.1.2.2	Data on: <ul style="list-style-type: none"> • Typical stress-strain curve of the prestressing steel; • Test results of ultimate strength, elongation, and composition of material not produced in accordance with an ASTM specification; • Values of the wobble coefficient and curvature coefficient, and the anchorage set data; • Test data substantiating the expected coefficient and anchorage set, if required.
9.1.2.3, 9.1.3	Data on actual material to be used in the Work: <ul style="list-style-type: none"> • Stress-strain curve for a sample taken from the production lot the prestressing tendons that will be used in the Work; • Certified mill test reports for the tendons, where required; • Results of tests required in 9.1.3.1 (test assembly, static test, cyclic test, grout testing).
9.2.1.1	Data demonstrating that strands, wire, and bars not listed in ASTM A 416/A 416M, A 421/A 421M, A 722/A 722M, and A 779/A 779M do not have properties that make them less satisfactory than those listed in these ASTM documents. Tendons should be fabricated in Post Tensioning Institute (PTI) certified plants.
9.2.1.7	Proposed locations of couplings at locations other than as indicated on the Contract Documents.
9.3.2.2	Data on field-applied coating for tendons extending outside the concrete or in concrete in severe exposures, or for tendons ungrouted for more than 28 days after tendon placement.
9.3.4.3	Records of measured elongation and gage pressure or dynamometer readings for the prestressing force.
Shrinkage-compensating concrete	
10.1.3.2, 10.2.3.2	Expansion test results for the proposed concrete mixtures.
10.1.3.3	Placing sequences before concrete being placed. It is critical that the concrete be placed in such manner that will permit the placement to expand. Consult ACI 223 for guidance.
10.2.3.3	Proportions and expansion test results for revised mixture proportions.